



REPORT:

Merricks Creek Estuary investigation and options analysis

October 2015



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Executive summary

Merricks Creek is located on the Mornington Peninsula, approximately 70 km south-east of Melbourne, and flows east along Balnarring beach parallel to Westernport Bay until it opens into an estuary at Somers. The Merricks Creek Estuary community has raised concerns over a persistent odour that is being produced from the estuary and a number of other issues that impact on the health, use and enjoyment of the estuary. The persistent odour has coincided with a period of time over which the estuary has been permanently open to Westernport Bay.

Introduction

Alluvium Consulting Australia Pty Ltd (Alluvium) has been engaged by Melbourne Water to undertake an assessment of the issues and options in the Merricks Creek Estuary. This investigation and report have been commissioned to identify and report on the estuary processes that have led to the odour production and the other issues of concern. The investigations and report have included a review of options that best address the outcomes sought for the estuary by the community and stakeholders. Melbourne Water has been supported in this initiative by Department of Environment, Land, Water & Planning (DELWP), Southern Rural Water and Mornington Peninsula Shire Council.

The approach adopted for the investigation was based on two phases:

Phase 1 Information gathering: This phase was founded on input from an agency and community working group established to guide and provide input to the investigation. The input has included observations on events that have occurred in the catchment and estuary, and desired outcomes for the estuary and catchment. The desired outcomes identified by the community working group were to develop practicable, sustainable solutions that enabled the following:

- to be able to enjoy active recreation (e.g canoeing)
- to enjoy passive recreation (i.e walking)
- to increase creek flows and create a healthy waterway that provides habitat for fish and birds.

The concerns raised by the community as adversely impacting these desired outcomes were:

- the level, frequency and persistence of the odour
- fish kills and algal blooms
- shallowing of the estuary reducing recreational canoeing opportunities.

Phase 2 Investigation phase: This phase began with the development of objectives that provide high level pathways toward resolving the issues of concern in the Merricks Creek Estuary. As part of this phase, an expert panel of estuary and coastal specialists was engaged to review the processes at work as well as the objectives and options for management.

It should be noted that this investigation and reporting has some limitations. It did not include any field sampling of the estuary, catchment, beach or bay environments, and no specific computer modelling was undertaken within this project.

Observations of estuary condition

Three themes emerged from the community consultations, the review of existing reports and the site visits. The observations and themes were summarised as:

- 1. Development and historical works.** Prior to the 1940's, the mouth of the Merricks Creek Estuary was located approximately one kilometre east of its current location and would regularly close over and break out at various locations along the sand berm. Coastal engineering works were undertaken in the 1960's and 70's to create a permanent mouth at its current location. The works included both a timber wall that provided longitudinal bank protection and lateral timber groynes attached to the timber wall.

Between the 1970's and 2010, the estuary was typically closed to the ocean, intermittently breaking through the sand berm before closing again. In 2011/12, a rock wall structure was installed to replace

decaying sections of the timber engineering works. Since September 2010, the estuary mouth has been continuously open.

The Merricks Creek catchment has also been highly modified by agricultural practices, cleared for grazing and with many on-farm dams constructed to for agricultural water supply. Residential development is increasing throughout the catchment with a recent shift from holiday houses to more permanent residential developments, resulting in increases in nutrients and sediments from stormwater. The local area has now been mostly sewered, however, it is likely that there has been septic tank leakage and overflow into the estuary. There may continue to be leakage from old tanks or properties that have not been sewered.

- 2. Estuary type and function.** Merricks Creek Estuary is considered to be an intermittent closed and open lake lagoon (ICOLL). While ICOLLs are common for wave dominated shorelines around southern Australia, the Merricks Creek Estuary is the only ICOLL in Westernport Bay, with all other estuaries in the bay being permanently open, tide-dominated estuaries.

Since September 2010, the estuary mouth has been continuously open, which indicates the estuary may no longer be functioning as an ICOLL. This current period of an open estuary has been observed to be more influenced by the tide, with the development of a sand delta within the estuary reducing water level and negatively impacting canoeing activities.

A channel has been observed to have been scoured adjacent to the recently constructed rock wall.

Sea grass has been observed to be accumulating in the estuary and lower reaches of the Merricks Creek, along with a black sludge and an odour consistent with hydrogen sulfide gas.

- 3. Habitat conditions.** Mangroves have started colonising the estuary since around 2010. The estuary has also experienced algal blooms and associated fish kills during summer months. The ibis rookery at the Coolart Wetlands may also be a source of nutrients to the estuary. The beaches around the Mornington Peninsular region provide habitat for the endangered Hooded Plover. Hooded Plovers forage in sea-grass and nest in dunes near the seagrass during summer.

Processes at work

Based on the observations and available science on the estuary, the processes driving the odour, fish kills and shallowing depth of the Merricks Creek Estuary were explored in detail. The key drivers were identified as follows:

- 1. Estuary mouth function.** Estuary openings and closures are driven through a combination of wave energy, tides and freshwater catchment flows. Catchment flows and high tidal ranges tend to create and maintain estuary openings, whereas low catchment flows, combined with large wave patterns that transport sand, contribute to estuary closure.

Whether the estuary mouth is open or closed has implications for other processes occurring through the estuary. An open estuary results in the transport of organic material (particularly mobile seagrasses) and sand into the estuary, however, a closed estuary can result in catchment derived nutrient accumulation within the estuary, driving algal blooms and fish kills.

This catchment and coast has experienced highly variable climatic conditions over the past 65 years, and was directly impacted by the Millennium Drought, followed by the high rainfall of the 2010-2012 La Niña event. Periods of heightened wave storminess have been recorded, with evidence suggesting the region could be experiencing such a period from 2010 until the present. The estuary is also impacted by the tidal forces of the Westernport Bay.

The rock wall built in 2011/12 could be contributing to a change in the balance of energy that drives sediment transport (erosion versus deposition) at the estuary mouth. The previous timber wall (replaced by the current rock wall) included a number of lateral timber groynes that protruded into estuary channel, providing a degree of 'roughness' that affected tidal and rainfall flows near the estuary mouth. This roughness is associated with the absorption of energy from runoff, tidal and wave energy and sediment deposition and accumulation. The newer rock wall does not feature this lateral roughness. This absence of roughness could be causing flow energy to be expended in local scour against the rock wall, resulting in a more deeply incised channel and reduced trapping of sand near the estuary mouth extending the duration of the estuary opening.

As this is a complex system, we have been unable to determine the degree to which each of these factors (wave energy, tides, catchment inflows or the rock wall) has contributed to the estuary's current state. We have, however, identified current research being undertaken in Melbourne that has developed a model that could assist in identifying the extent to which the extended period of estuary opening is a natural occurrence or whether an additional factor (such as reduced estuary channel roughness) explains the extended period of estuary opening.

- 2. Hydrogen sulfide.** Available evidence suggests the persistent odour at the Merricks Creek Estuary is hydrogen sulfide (H₂S, rotten egg gas). Hydrogen sulfide is the product of the anoxic decomposition of organic matter in the presence of sulfates. Sulfates can be found in seawater. The rate of decomposition increases during summer which explains why residents have observed that the smell is worse over the warmer seasons.

Alluvium has found the primary source of organic matter driving the hydrogen sulfide production in the estuary to be seagrass. We have found sea grass to build up on the Balnarring Beach around August/September and to then be transported through longshore (lateral) drift to the mouth of the open estuary. The daily tidal action into and out from the open estuary results in the transport of this sea grass into the Merricks Creek Estuary, where it accumulates. Organic material in the estuary is also sourced from catchment inflows and existing deposits. However, we found the volume of sea grass to have accumulated in the estuary to be several orders of magnitude (100 to 1000 times) more than the volume derived from catchment sources.

The anoxic decomposition (i.e. decomposition under low oxygen conditions) of the accumulating seagrass within the estuary has arisen as a result of the continued open state of the estuary. This decomposition has resulted in the persistent release of hydrogen sulfide.

Hydrogen sulfate gas is also released when acid sulfate soils are exposed to oxygen. This continually occurs through the wetted and drying associated with tidal events.

- 3. Water depth.** The observed shallowing of the estuary is a function of both the transport of sand into the open estuary through daily tidal movements and through the daily ebb and flood tide variations.
- 4. Fish deaths** are likely to be associated with a decline in dissolved oxygen in the water column. The low dissolved oxygen can be caused by either algal blooms or through a process whereby hydrogen sulfide released into the water column through anoxic decomposition of the sea grass is oxidised by the dissolved oxygen contained in the water column. This oxidation process can consume the available oxygen in the water column, leading to low dissolved oxygen levels and fish deaths.

Options and recommendations

The community has sought to achieve a reduction in the persistent odour in the area of the estuary, improved recreation boating (through increased estuary depth) and reduced fish kills. However, due to the complexity of the issues and processes, we have found no simple solution that satisfactorily achieves these management outcomes.

Sea grass removal from beach: We do not recommend removal of sea grass from Balnarring Beach before it can enter the estuary as a means to prevent the odour production. The beach and sea grass provides habitat for the Hooded Plover that would be impacted by removal operations. In addition, the ongoing sustainability of such an approach (in terms of cost, environmental and social impacts) means this is not a preferred option.

Sea grass removal from within estuary: We do not recommend options to capture and remove the sea grass from within the estuary as this would be extremely complex, and require ongoing management and maintenance.

Estuary closure to prevent sea grass entering: We prefer an option that focuses on achieving estuary closure as the primary mechanism to prevent sea grass entering the estuary. Such an approach would also address the water depth and recreational boating. We propose that work to achieve this outcome occur as soon as practicable to prevent further influx of sea grass to the estuary.

However closure of the estuary also poses some risks. These risks include nutrient accumulation, algal events and associated fish kills. Closure could also pose a public health risk this summer. These risks are discussed below.

Nutrient accumulation and algal events: In the long term we propose that the risks of nutrient accumulation and algal events be managed by:

- Allowing breaches of the estuary during flood events. Breaches of the estuary mouth (i.e. the natural opening of the estuary) during significant rainfall and runoff events will assist the beneficial flushing of nutrients from the estuary. As a consequence, we do not favour options and works that will permanently close the estuary.

We prefer options that assist the natural closure of the estuary, and allow opening of the system during significant runoff events. We propose the installation of works that replicate the 'roughness' provided by the lateral groynes that were present on the old timber wall as a means of trapping sand at the mouth of the estuary. This will assist closure and allow natural openings of the estuary.

- In the medium and longer term, we propose catchment management programs to reduce nutrient loads to the estuary.

Public health: We are concerned that hydrogen sulfide accumulations could cause a public health hazard this summer if the estuary is closed while there are significant amounts of sea grass present in the estuary and this is combined with very warm and still weather conditions. We expect that this risk will only be present in the short term during the period over which the existing sea grass within the estuary decomposes. Seagrass decomposition is expected to take about 100 to 200 days, so once we can stop the seagrass from entering the estuary in large quantities, the risk will cease after around 4-8 months.

At high concentrations, hydrogen sulfide is a hazard to human health. However, this hazard only occurs in parts of the estuary that sit lower than the sand berm and at times of very still conditions where there is no wind.

While the likelihood of such high accumulations of the gas is low, the consequences could be very high. We rank the risk to public safety as high and recommend appropriate management attention to address this risk. The risk will be highest over the summer period with the potential for high rates of sea grass decomposition and with high numbers of campers and other holiday makers within close proximity to the estuary.

Any breeze through the estuary prevents the settling of hydrogen sulfide in low lying areas, and mixing it with air reduces the risk of gas accumulations. However, during very still evenings with no wind movement, it may be possible for hydrogen gas to not mix with air and to settle in low lying areas adjacent to the estuary.

Over the period that the estuary has been open, the hazard associated with this settling has been low as the gas drains out through the open estuary mouth, preventing any significant accumulations. There is a risk that on a windless evening, the sand berm that has closed the estuary may prevent such 'drainage', allowing the accumulation of hydrogen sulfide.

There is a risk of algal blooms and declining estuary water quality this summer with a closed estuary.

We propose two alternate options to address these short term risks.

Recommended options

Option 1: immediate installation of interim works to assist estuary closure, preventing new seagrass entering the estuary.

We propose that these interim works comprise construction of sand groynes that result in the closure of the current tidal channel. These works could then be removed and or allowed to collapse prior to summer and as a result, re-establish an open estuary over the forthcoming peak summer period, reducing the risk of adverse water quality and public health outcomes. This is a short-term solution.

More permanent or replacement works could then be installed in autumn.

Pros/cons of this approach:

This option has the benefit of preventing the large load of sea grass currently on Balnarring Beach from entering the estuary and hastening the conclusion of the decomposition process. However, it

will result in duplication of some effort as the works may need to be replaced by more permanent arrangements.

Option 2: delay the installation of works until after the summer of 2015/16.

This option avoids the potential duplication of effort but comes at the cost of allowing more sea grass to enter the estuary, delaying the conclusion of the sea grass decomposition. This option reduces the public health risk over this 2015/16 summer period associated with the build-up and containment of hydrogen sulphide.

Evaluation of options and deciding on the way forward

We propose that these two options be canvassed with the agency and community working group established for this project.

In addition to these options, and in the short term, we propose:

1. An **investigation** be undertaken (based on research from University of Melbourne) using the recently developed model to identify the extent to which the open estuary condition can be attributed to wave energy, tides and catchment inflows. The output from this investigation would be used to assist the design of longer term intervention works.
2. The development of longer term **design** arrangements for works to re-establish an estuary opening and closing regime, which reduces sea grass influx to the estuary without impacting on estuary openings during high flow events. We propose that these longer term works be installed in autumn 2016.

The proposed short term program of management, for the period October 2015 to March 2016, is set out in Table 1.

Table 1. Expected timelines of the two short term management options

		Option 1: Immediate interim works	Option 2: Delay works until after 2015/16 summer
		<i>Advantages:</i> <ul style="list-style-type: none"> • Prevents further seagrass entering estuary over Nov/Dec • Earlier resolution of odour issue <i>Disadvantages:</i> <ul style="list-style-type: none"> • Duplication of effort 	<i>Advantages:</i> <ul style="list-style-type: none"> • Less cost, more efficient use of limited resources <i>Disadvantages:</i> <ul style="list-style-type: none"> • Odour will be around for longer
Timeline	Investigations		
Oct 2015	Co-ordinate arrangements		No physical works
Nov 2015	Explore model to better understand cause of persistent estuary opening	Install interim works to assist estuary closure and stop more seagrass from entering estuary	
Dec 2015	Monitor and evaluate results of interim action	Remove interim works or allow interim works to collapse to reduce short term adverse public health and water quality risks over peak tourism season	
Jan 2016			
Feb 2016	Refine approach to longer term works to implement based on investigations		
Mar 2016	Monitor long term solution.	Implement longer term works solution	Implement longer term works solution

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Glossary and abbreviations

Bar	The temporary sand barrier that separates the Merricks Creek Estuary from Westernport Bay
Berm	A raised barrier that separates two areas. In this case, the berm is the coastal sand barrier that separates Westernport Bay from Merricks Creek.
Coriolis effect	The Coriolis effect is a result of the Earth rotation and causes ocean currents and tides to follow curved paths
DELWP	Victorian Government Department of Environment Water Land and Planning
Ebb tide	Low tide
Estuary	A transitional zone where the river mouth connects with the open sea's tide.
Flood tide	High tide
ICOLL	Intermittently Closed and Open Lake Lagoon
Longshore drift	The transportation of sediments and sand (and sea grass) along the coast at an angle to the shoreline, dependent on wind and wave action
Roughness	A hydraulic measure of the amount of frictional resistance when passing over land or channel features, such as the Rock Wall at Merricks Creek Estuary
Storminess	Heightened wave action
SOI	Southern Oscillation Index
SO₄²⁻	Sulfate
S²⁻	Sulfide
H₂S	Hydrogen sulfide

1 Introduction

Alluvium has been engaged by Melbourne Water to undertake an assessment of issues and options in the Merricks Creek Estuary. The Merricks Creek Estuary community have raised concerns regarding a persistent odour that is being produced from the estuary and a number of other issues that impact on the use and enjoyment of the estuary. This persistent odour has coincided with a period over which the estuary has been permanently open to Westernport Bay.

This investigation has been undertaken to identify the processes that have led to the odour production and the other issues of concern, together with options that best address outcomes sought for the estuary by the community and stakeholders.

This report sets out the issues, the approach adopted for the investigation, the results of the investigations and options to address the issues of concern.

1.1 Study aims

This Merricks Creek estuary investigation and options analysis has been undertaken, with Melbourne Water, other government agencies and the community to:

- Review background documentation
- Explore the physical, chemical and biological estuary processes and their relationships with both Westernport and upstream catchments
- Identify the processes contributing to the issues of concern to the community
- Analyse, from a scientific and engineering perspective, the proposed options for odour remediation and advise on the potential for success
- Produce a report that documents the detail behind each option, including likelihood of improving odour, cost, risks and associated multiple benefits.

1.2 Stakeholder engagement and timeline

The investigation has been undertaken in association with, and with input from, agency and community representatives, forming a Merricks Creek Estuary Working Group. The working group has comprised representatives from:

- Melbourne Water
- Victorian Government Department of Environment Water Land and Planning (DELWP)
- Mornington Shire Council
- Southern Rural Water
- The Somers and Balnarring community.

Meeting No. 1: The first meeting was held in May 2015, prior to the commencement of this investigation. At this meeting the issues of concern were discussed and the composition of the Merricks Creek Estuary Working Group established.

Meeting No. 2: At the second meeting held in June 2015 (attended by Alluvium largely as observers), a working group brief was developed for the scope of this project. This scope outlined the desired outcomes of the project including:

- A range of options over different time frames
- A process that works and actually reduces the odour
- To better understand what is causing the problem
- A healthy waterway (end to end).

Meeting No. 3: At meeting No. 3 in July 2015, Alluvium discussed the results of the field observations and identified priority areas for further and more detailed investigations to be undertaken as part of the investigations.

Expert Review: in August 2015, a workshop with technical specialists, referred to as the expert panel, was held. The expert panel contributed specialist knowledge and expert science to assist in developing an in-depth understanding of the processes being observed at the Merricks Creek Estuary. The people on the expert panel included:

- Christine Lachlan Arrowsmith, expert on coastal processes, Water Technology
- Vanessa Wong, expert on acid sulfate soils, Monash University
- Perran Cook, expert on estuarine water quality, Monash University
- Paul Hodgson, Melbourne Water

Additional experts were also interviewed to address additional knowledge gaps identified throughout the investigation. These included:

- Sarah McSweeney, expert on estuarine geomorphology, The University of Melbourne
- David Kennedy, expert on estuarine geomorphology, The University of Melbourne.

Meeting No. 4: *Pending completion of final report – October 2015.*

1.3 Study area

Merricks Creek is located on the Mornington Peninsula approximately 70 km south-east from Melbourne (Figure 1 and Figure 2). The headwaters are located near Red Hill South and Merricks North. The creek flows south-east to Balnarring Beach where it drops down from its terrace onto a lower coastal plain, transitioning to an estuary. The Merricks Creek Estuary runs east from Balnarring Beach, parallel to the Westernport Bay shoreline over a distance of approximately 2.5km, until its opening to Westernport Bay at Somers. The Merricks Creek has a catchment area of 52 km² comprising urban areas (including the developing towns of Balnarring and Merricks), and rural lands developed for agriculture (grazing, orchards, vineyards, and nurseries). Many farm dams have been constructed to provide a water supply to agricultural operations. The estuary itself is separated from Westernport Bay by a well-vegetated frontal dune (sand barrier). The sand barrier is a site of regional geomorphic significance as it is rare in Westernport Bay and provides a clear example of a multiple barrier system (Rosengren 1984).

Merricks Creek is part of Melbourne Water's South-Eastern Peninsula Rivers and Creeks management unit. Merricks Creek estuary is a priority area for improving vegetation In Melbourne Water's *Healthy Waterways Strategy*, while the Lower Merricks Creek is a priority area for maintaining amenity.

For the purpose of this investigation, the study area has been divided into three reaches (from downstream to upstream):

- Reach 1: Estuary mouth to the second bridge (upstream extent of Lord Somers Camp)
- Reach 2: The second bridge to tidal extent, including Tulum Creek (Home Creek)
- Reach 3: Upstream of tidal extent, including tributaries.

Tributaries: of Merricks Creek include Merricks Creek East and West Branches, Tulum Creek and Coolart Creek.

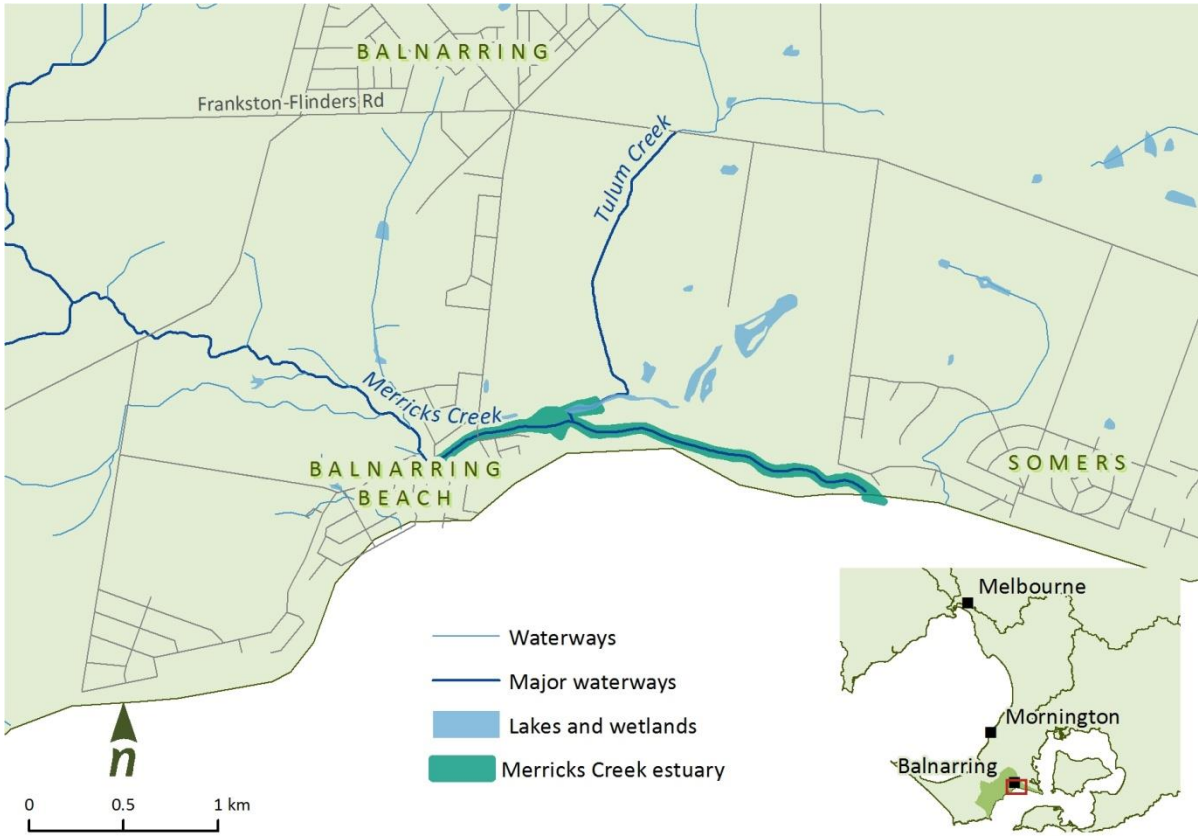


Figure 1. Study area

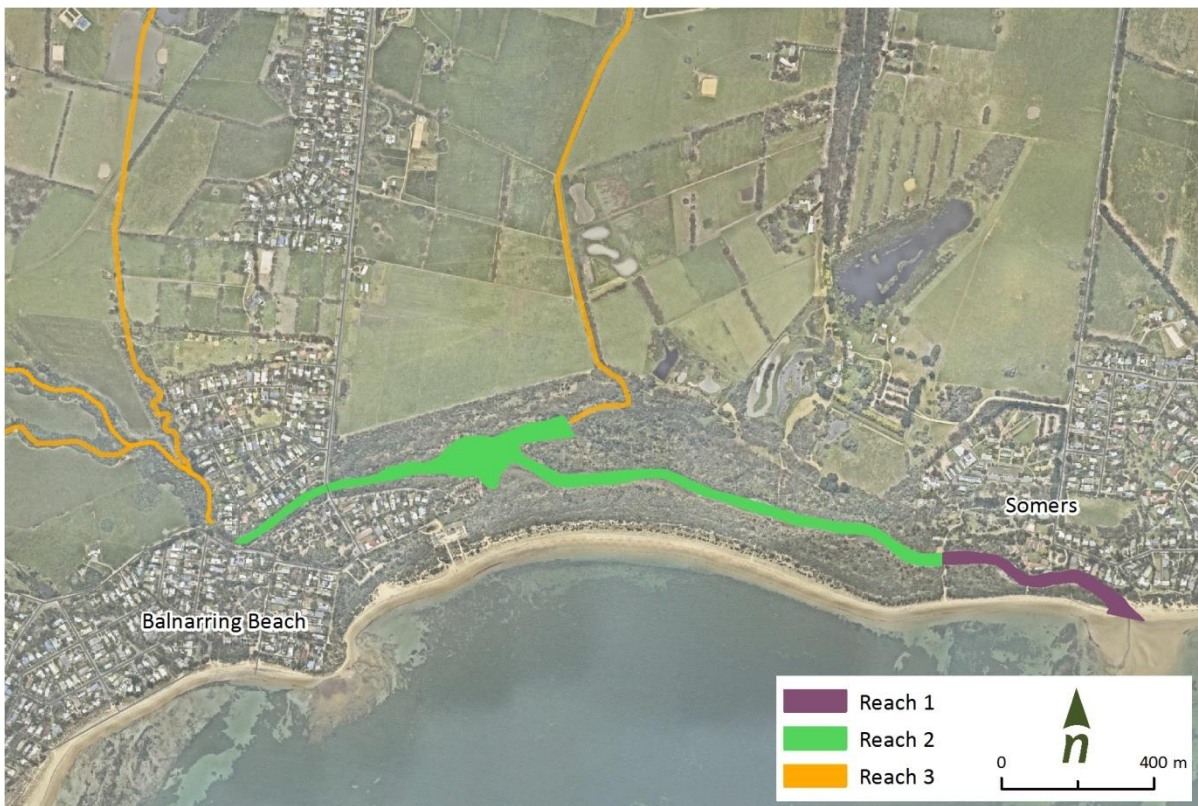


Figure 2. The Three Reaches of Merricks Creek and the estuary

1.4 Approach and report structure

The approach adopted for this investigation is set out in Figure 3. The approach has been based on two phases

Phase 1 Information gathering: This phase was founded on input from the community working group including observations on events that have occurred in the catchment and estuary, and desired outcomes for the estuary and catchment. The observations from the community, site visit and previous reports are discussed in chapter 2 of this report. The collation of the observations has informed a discussion on the many processes occurring in the estuary, set out in chapter 3 of the report.

Phase 2 Investigation phase: The identification of desired outcomes, the collation of observations and the development of a preliminary understanding of processes at work within Phase 1, enabled the Phase 2 investigations to focus on a limited set of potential processes. This Investigation phase has included targeted literature review, subsequent field inspections, a workshop with technical specialists (expert panel), discussions with estuary researchers and some limited quantitative analysis of organic loads to the estuary. These investigations were undertaken to develop a more detailed understanding of the processes at work (refer Chapter 4)

The phase has also included the development of objectives for the system, providing high level pathways that assist to resolve the issues of concern in the Merricks Creek Estuary. Options for management were developed and are set out in Chapter 4 of the report. This section includes a discussion on the feasibility, cost, maintenance and sustainability of possible actions. Recommendations are provided in chapter 5. This chapter sets out the preferred management actions to meet the objectives and desired outcomes.

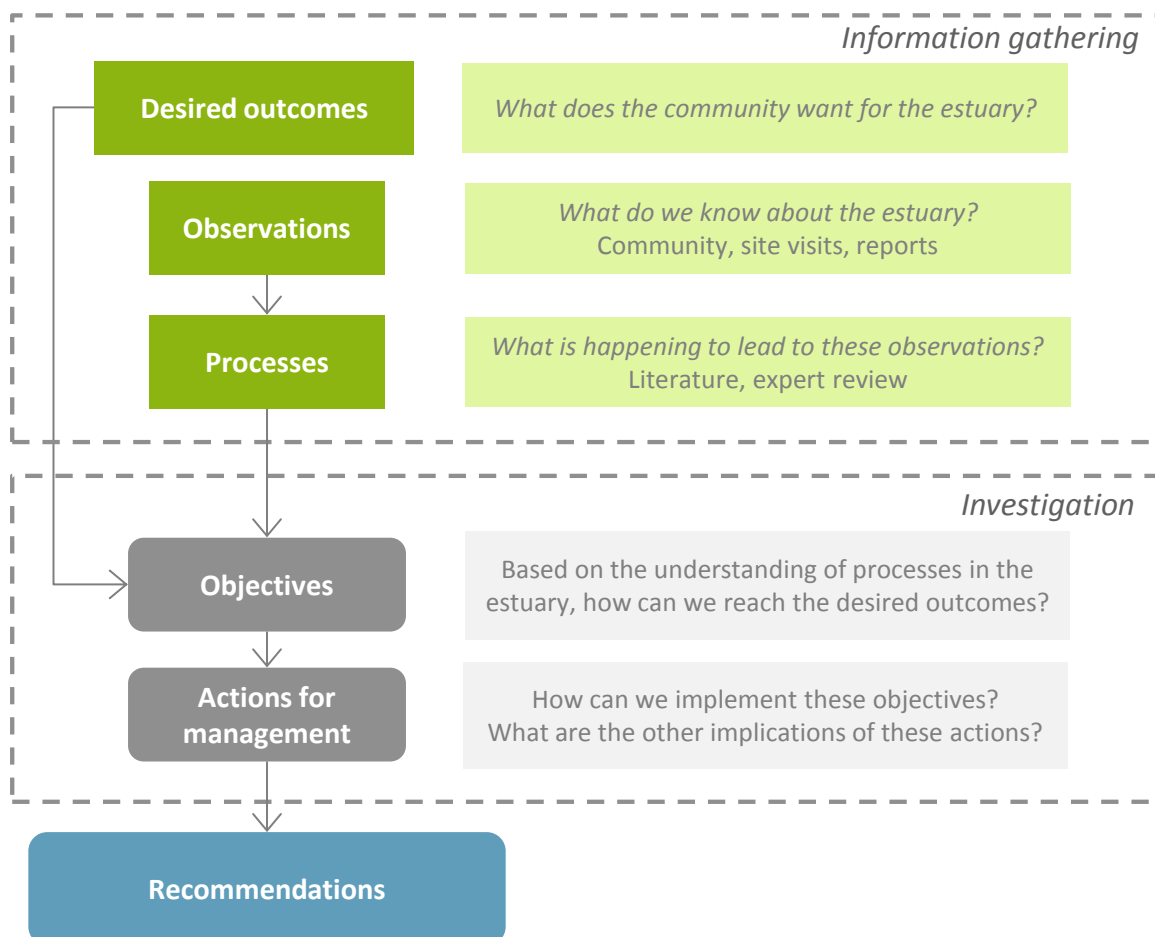


Figure 3. Approach to investigation

1.5 Desired outcomes for the estuary

During the second community meeting undertaken as part of Phase 1, a working group brief was developed for the scope of this project. Desired outcomes from the project sought by the community have been previously set out in Section 1.2 of this report. Through the process of developing the desired outcomes from the project the community also identified the following desirable outcomes for the estuary:

- to be able to enjoy active recreation, e.g. canoeing (but not necessarily swimming)
- to enjoy passive recreation, i.e. walking and being around it
- the creek to have greater flows, and be a healthy environment for fish and birds (but acknowledge that it doesn't have to be pristine)
- to acknowledge that C Reserve is an important recreational feature of the local area and important for local tourism.

At this meeting, members of the community working group identified three processes that adversely impacted on these outcomes and the enjoyment of the estuary:

- the level and persistence of odour: Members of the community working group advised that odours in the estuary were present 'all the time'
- the shallowing of the estuary: Members of the working group advised that participants at the local camps could no longer reliably launch and paddle canoes in the estuary as a result of recent shallowing
- fish kills: Members of the working group expressed concern regarding past and ongoing fish kills in the estuary.

Based on our understanding of the issues and in the context of this study, the desired outcomes for the estuary have been refined as the provision of:

- Acceptable level of odour and avoidance of prolonged periods of unpleasant odour
- Reduced occurrence of fish kills and ideally no fish kills
- Suitable water depth for launching and enjoyment of recreational boating (row boat and canoe).

Through this investigation we have sought to identify the processes at work, the range of options to address these processes and a preferred option or set of options that provide the desired outcomes for the estuary and community.

2 Observations

Observations were collected through community consultation, review of existing reports and observations and discussions during a site visit (further detail is provided in Attachment A). This information forms the beginning of the Merricks Creek story, upon which the basis of this report is formed.

The observations are summarised in the timeline and map below (Figure 4 and Figure 5). They are described in further detail in this chapter. The timeline does not use a consistent time scale, rather it focuses on the changes occurring in recent years. The shading of the boxes increases from light to dark, where a significant change has occurred.

Throughout the discussion on observations and subsequently processes, the following four themes are considered, with associated colours and symbols (Table 2).

Table 2. Themes for observations

Theme	Colour	Symbol
Development and works	Orange	
Estuary function	Red	
Climate and water quality	Blue	
Biota	Green	

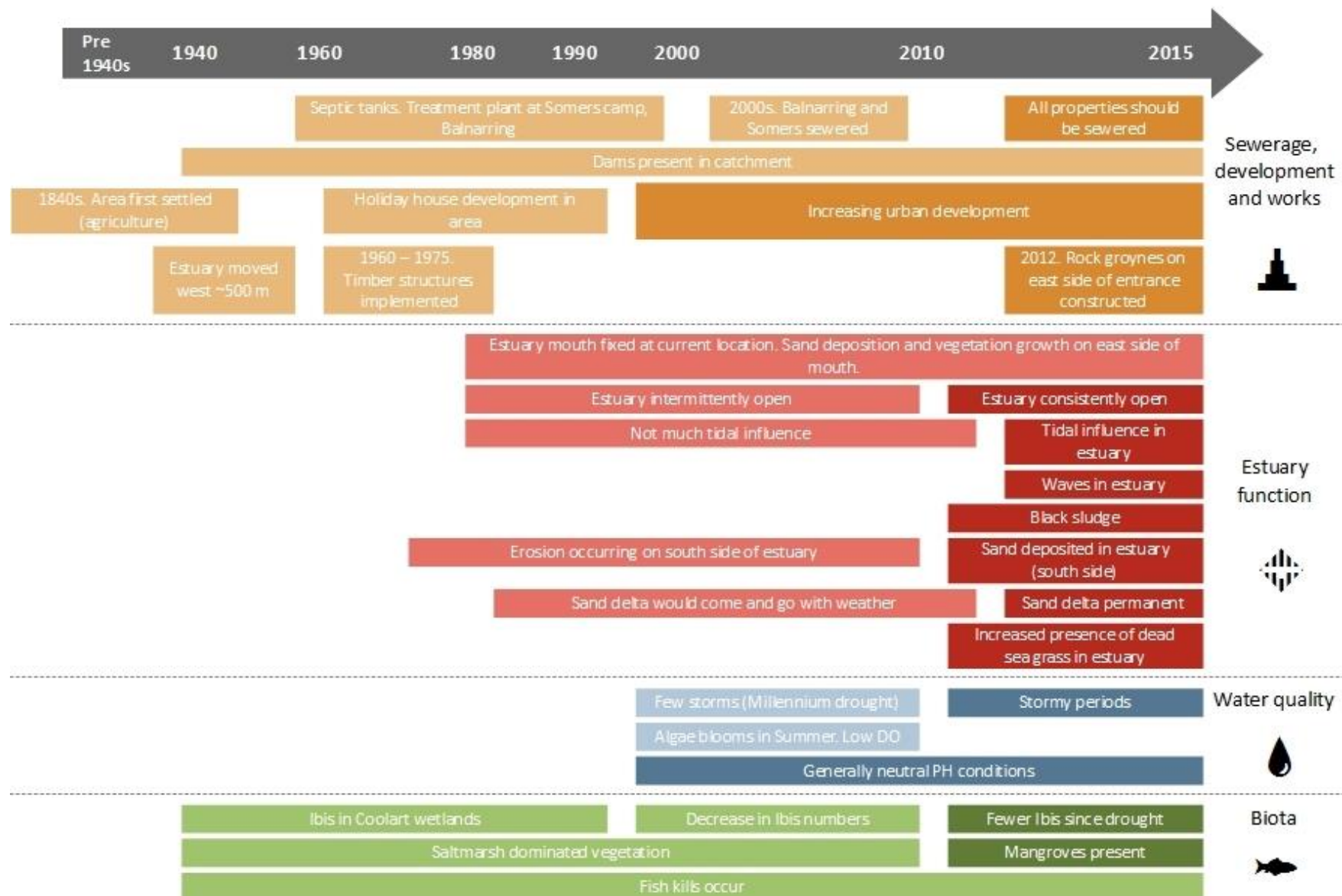


Figure 4. Timeline of collated observations (note Millennium Drought from 1997 to 2009)

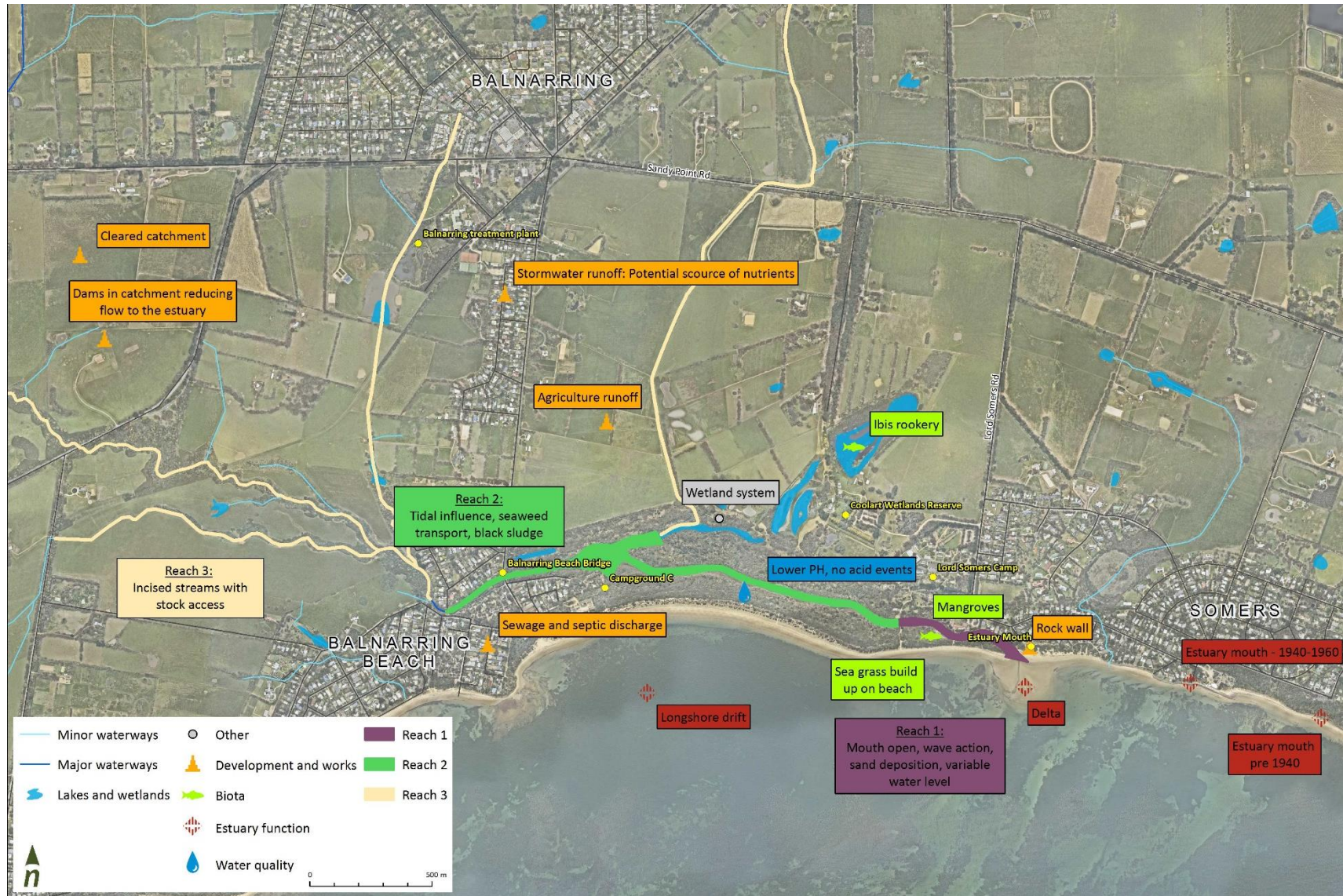


Figure 5. Map of collated observations

2.1 Development and works

Coastal works

Prior to the 1940's the mouth of the Merricks Creek Estuary was located approximately 1 km further east than the current location (see DLS 1959; GHD 2003). Up until this time, the estuary would regularly bar over and break-out along various other locations along the sand berm (Figure 6 and Figure 7).



Figure 6. Estuary mouth locations through time

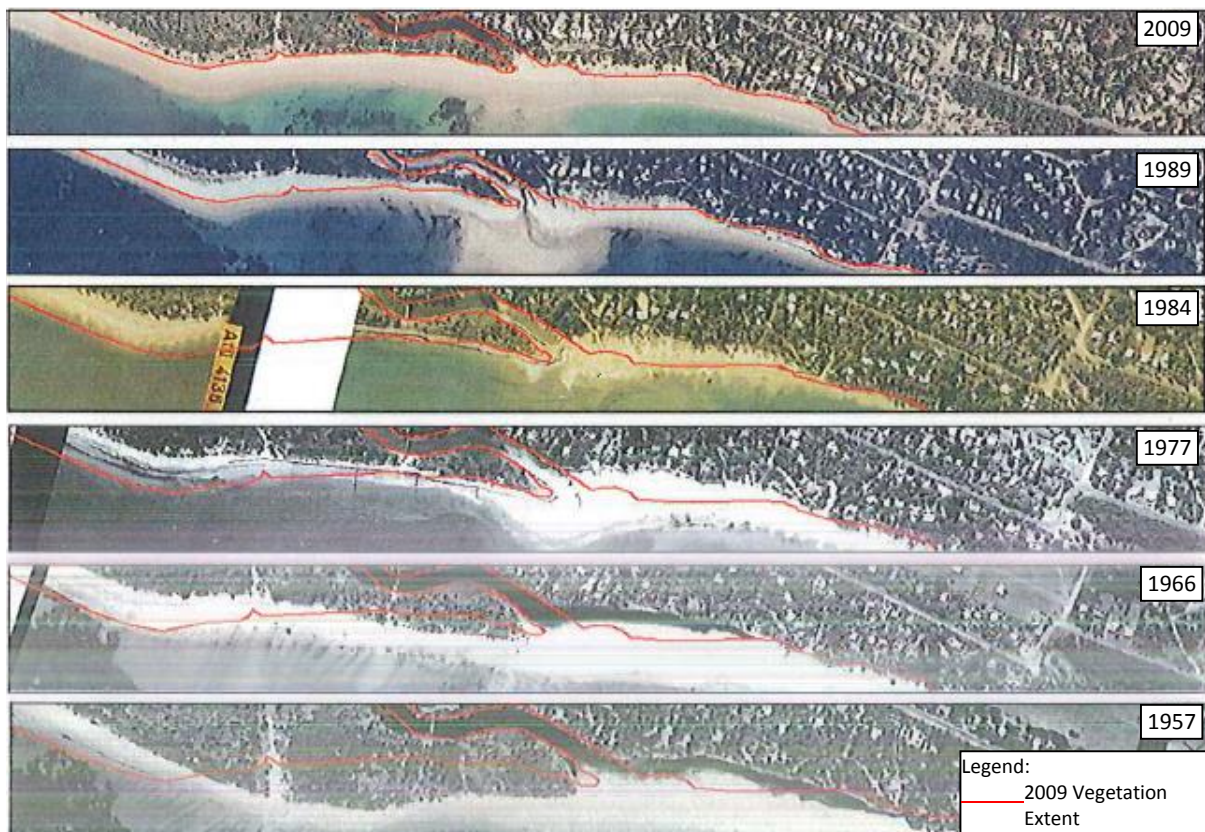


Figure 7. Historical coastline variability analysis (Water Technology 2011)

From the 1960s to 1975, coastal engineering work were undertaken to 'fix' the estuary mouth at its current location. These works included:

- timber training walls with lateral spur dykes at the estuary mouth, and
- a sea wall with lateral groynes on the west beach (Figure 8).



Figure 8. Works undertaken 1960-1975 – aerial photo ~1977 (Water Technology 2011) timber training wall shown in red and timber sea wall shown in green

From the 1970s to 2010, the estuary was typically closed to the ocean, with intermittent periods where the sand bar at the estuary mouth would break open before again closing. In 2011/2012 the failing timber structure on the east side of the mouth was replaced with a rock structure (Figure 9) to ensure the continued protection of the adjacent houses.



Figure 9. Rock wall and timber structure, looking across mouth from west to east (old timber structure on west side of estuary in foreground, with new rock wall on east side in the middle ground) (Source: Alluvium, 2015)

Development and agriculture

There has been increasing residential development through the Merricks Creek Catchment, with a shift from agriculture and holiday houses to more permanent residential development and use.

Agriculture has heavily modified the catchment in time, with dams present throughout the catchment. The creek is subject to pressures associated with past vegetation clearing and ongoing grazing practices.



Figure 10. *Merricks Creek (reach 3)* (Source: Alluvium, 2015)

Sediment and nutrient loads have been identified as impacting the Merricks Creek and the estuary (Arundel & Barton 2007; AWT 1998). High levels of sediment and nutrient loads may be due to stormwater from surrounding towns (Balnarring, Red Hill South, Merricks, Somerville), septic tank leakage and runoff from rural lands (Arundel & Barton 2007; AWT 1998; GHD 2003).

2.2 Estuary functions

Estuary opening

The Merricks Creek Estuary is considered an intermittently closed and open lake lagoon (ICOLL), having been observed to be closed most of the time with intermittent openings. While common for wave dominated shorelines around southern Australia, the Merricks Creek Estuary is most likely the only ICOLL in Westernport Bay, with all other estuaries tide-dominated.

However, since September 2010, the estuary mouth has remained continuously open.

Greater tidal influence

Since the estuary mouth has remained open, it has been observed to be more influenced by the tide. This has included wave action entering the estuary during high tide, greater sand deposition and the development of a permanent sand delta. This has reduced the water level, negatively impacting recreational canoeing opportunities.

Also observed is wave and tidal scour adjacent to the wall, as observed by the channel of water present along the rock wall in Figure 11.

There is also some evidence of increased periods of storminess (wind) having a negative impact on the condition of the estuary.



Figure 11. *Estuary mouth, looking downstream (south)*

Black sludge and odour

Black sludge and a persistent odour have been observed in the lower reaches of Merricks Creek. The odour is thought to be consistent with that of hydrogen sulfide (rotten egg) gas, and is likely to be resulting from the black sludge.



Figure 12. *Seagrass and black sludge in estuary through reach 1(left) and 2 (right) (August 2015)*

Sea grass

Seagrass has been observed building up on the west beach and also throughout the estuary. The sea grass is dead material that, when exposed to air, dries out and is readily transported through water movement.



Figure 13. *Balnarring Beach looking west from mouth showing accumulation of dead sea grass (August 2015)*



Figure 14. *Seagrass in estuary through reach 1 (August 2015)*



Figure 15. *Seagrass in estuary through reach 2 (August 2015)*

2.3 Biota and water quality

The Ibis rookery at the Coolart Wetlands has been identified as a potential source of nutrients and sediments to Merricks Creek and the estuary (GHD 2003). Additionally, a decrease in ibis numbers has been observed since the Millennium Drought.

Algal blooms and fish kills have been reported to have occurred frequently during periods when the estuary was closed, particularly during the summer months. We understand that a fish kill also occurred in the summer of 2015.

Mangroves have been observed to have started colonising the estuary since around 2010, this is thought to be associated with an increase in the salinity of the creeks lower reaches, and the development of intertidal sand bars.

The beaches around the Mornington Peninsular are known habitat for the Hooded Plover, listed as Endangered in Victoria. With less than 600 individuals left in the state, the highest densities of Hooded Plovers occur on beaches and estuaries with large amounts of beach-washed seaweed during any stage of their life cycle, especially during breeding season. The hooded plover nests above the high-tide mark on ocean beaches with the breeding season coinciding with peak summer holiday season. High incidences of nesting failure result from the crushing of eggs by off-road vehicles, disturbances by people and dogs, predation and ill-considered beach erosion management (Birdlife International undated).

2.4 Condition

Limited data exists on the condition of Victoria’s estuaries, impeding the development of an effective condition assessment tool. While an Integrated Estuary Assessment framework was developed by the Queensland EPA (Moss et al 2006), the only publically available information on the condition of Victorian estuaries was an assessment undertaken as part of the 2008 Victorian State of the Environment report. The report observes “there is limited data available on the ecological condition of estuaries and so the degree to which they are modified from a ‘near pristine state’ is used as an indicator of the state of the coastal environment” (SoE 2008 p 437). That report builds on the OzCoast estuary data, which rates 24 estuaries in Victoria as: near pristine, largely unmodified, modified or extremely modified.

Merricks Creek Estuary is not included in the OzCoasts data, however it would most likely be considered as either ‘largely unmodified’ or ‘modified’ based on the catchment land-use change and engineering works present at the site.

Estuary Watch is a community based estuarine monitoring program where volunteers regularly record data on estuary mouth condition and water quality. The estuary watch website (estuarywatch.com.au) has published monitoring information on three estuaries in eastern Victoria; Balcombe Creek Estuary, Coal Creek Estuary and Powlett River Estuary.

The Index of stream condition undertaken across Victoria, includes the streams of the Mornington Peninsular, but not Merricks Creek. Figure 16 shows neighbouring Stoney Creek and Warringine Creek to have been assessed as being in ‘moderate’ condition (DEPI 2010).



Figure 16: Index of stream condition results Source: DEPI 2010

3 Processes

A conceptual model of the processes at work in the Merricks Creek Estuary has been developed for this project (Figure 17). This model has been based on the collation of detailed observations and available science on estuary processes.

The conceptual model has been structured around the three unfavourable outcomes that have been raised by the community:

- Odour
- Fish kills
- Shallow water level.

The key drivers of these outcomes have been identified as

- The estuary mouth function (estuary opening and closing)
- The release of hydrogen sulfide gas associated with the anoxic decomposition of organic matter in the presence of sulfidic material (sea water)
- Organic matter in the estuary
- Dissolved oxygen in the estuary
- Water depth.

This chapter discusses some of the key processes in detail.

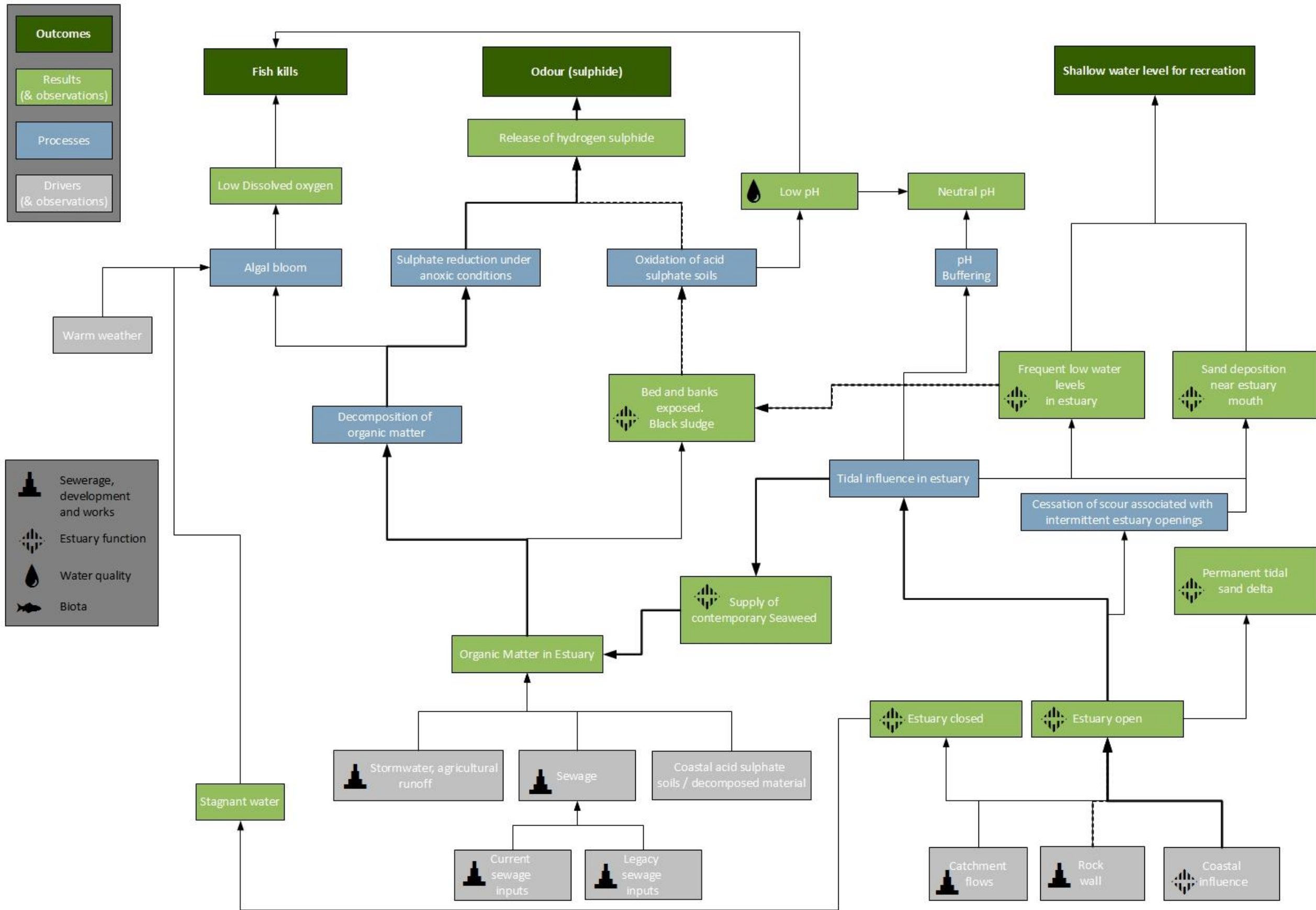


Figure 17. Conceptual model for processes at Merricks Creek

3.1 Estuary mouth function

The state of the estuary mouth (open or closed) has implications for other processes occurring throughout the estuary and as a consequence is a convenient place to commence a discussion on the processes at work.

An estuary's geomorphology, and hence its shape and form, are influenced by wave, tide and river forces. The relationship between these forces and estuary form are shown in Figure 18.

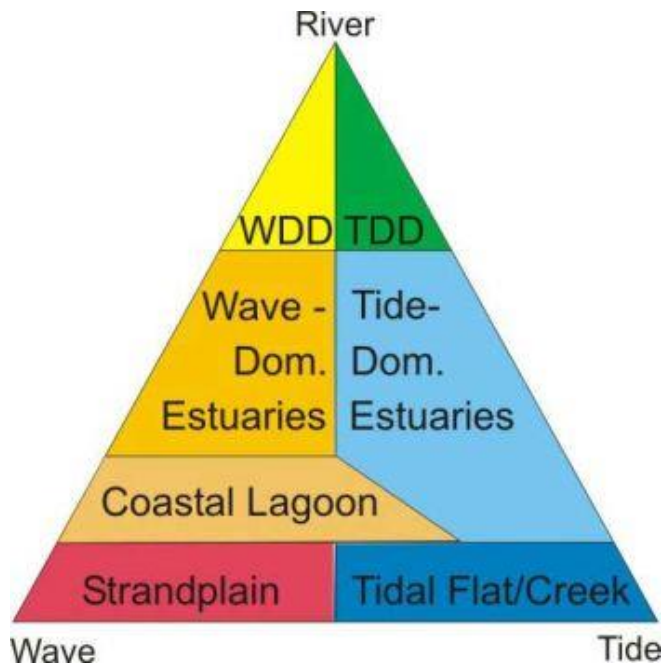


Figure 18 Relationship between river, wave and tide on estuary type (from: OzCoasts 2015)



Figure 19 Examples of wave dominated (left) and tide dominated (right) estuaries (from Short and Woodroffe 2009)

Wave dominated estuaries are shaped by the force and sediment transport of oceanic waves. Sediment 'dumped' by large wave action results in the development of a sand berm (or bar) across the mouth of the estuary, closing it off from the ocean at the high tide line. Periods of high river inflows from the catchment then break open the berm, opening the estuary to the ocean again. Wave dominated estuaries and related coastal lagoons are often referred to as 'intermittently closed and open lake lagoons' (ICOLL) and are common around the exposed coasts of southern Australia with high wave energy and limited tidal range. Just over half of Victorian estuaries have entrances that are naturally closed by sand bars from time to time (Corangamite CMA 2012). For example the Anglesea, Snowy and Gellibrand River estuaries are all ICOLL estuaries.

Tide-dominated estuaries are shaped largely by tidal currents. Always open to the ocean, sediment is transported by the tidal currents as well as catchment inflows to infill the estuary. This results in the creation of tidal sandbanks and intertidal flats in which salt tolerant vegetation, such as mangroves, colonise.

Catchment inflows often incise narrow channels across the flats of the estuary. Tide dominated estuaries are typically found along northern Australian coasts where there is greater tidal range and reduced wave energy. Such estuaries can also be found in protected bays where tidal forces dominate over wave forces.

The Merricks Creek Estuary is considered an ICOLL, and while common for wave dominated shorelines around southern Australia, it is the only ICOLL in Westernport Bay. The other estuaries including Cardinia Creek, the Bunyip River and the Lang Lang River are all tide-dominated estuaries.

However since September 2010, the estuary mouth has remained permanently open. This is unusual as prior to 2010 the estuary had been observed to be closed most of the time and to have opened only intermittently. In line with many of the other observations noted in Chapter 2, the estuary is now functioning in a similar manner to a tide-dominated estuary.

There are three primary implications associated with the open estuary:

- greater tidal variation within the estuary
- transport of sand into the estuary
- transport of organic material (sea grass) into the estuary.

However closure of the estuary will result in previously observed adverse impacts, namely:

- nutrient accumulations
- increased biochemical oxygen demand
- reduced dissolved oxygen levels.

The relative influence of wave action, tidal process and freshwater inflows from the catchment are explored as they relate to the Merricks Creek Estuary. In addition to these natural processes, the role that the rock wall may have on the estuary remaining open is also explored.

The following sections are the result of a review of readily available science and the specialist input from experts on coastal process (Christine Lachlan Arrowsmith, Water Technology) and estuarine geomorphology (Sarah McSweeney, University of Melbourne).

Wave action in Westernport Bay

Waves are associated with the transportation of sediment and the closing of ICOLLs. There is limited wave data available for Victoria's coasts. Past studies on of wave direction show swells enter Westernport Bay from a south-westerly direction.

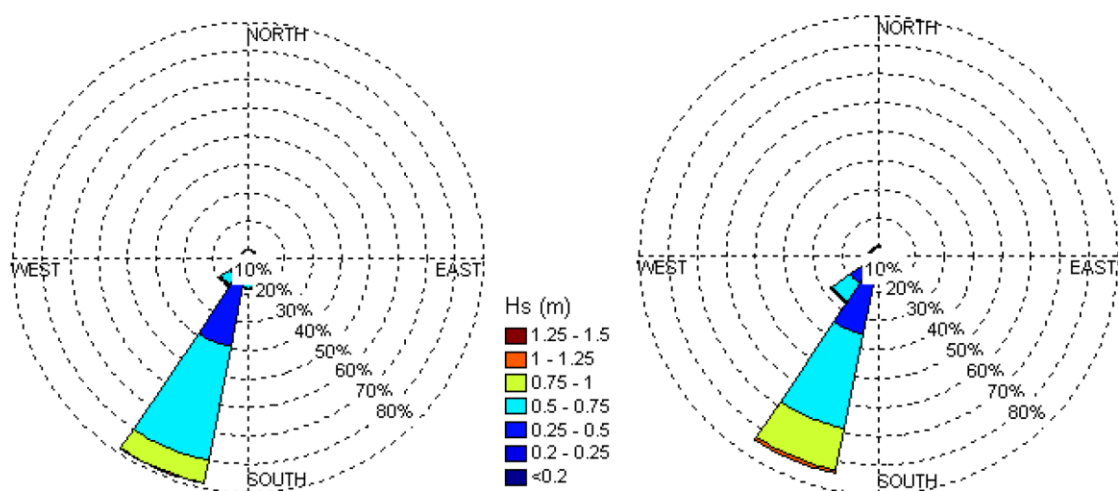


Figure 20. Wave Roses – Summer (2003) and Winter (2003) (Water Technology 2014)

Wave action is also influenced by storm events. Analysis of storm events on the Gippsland coastline reveals periods of heightened storminess during the 2007 to 2011 period (Water Technology 2014). Anecdotal evidence suggests that a period of heightened wave storminess has continued through to 2015. Water Technology has found recent coastal erosion across Victoria to be associated with a recent period of heightened 'storminess'. However, recent unpublished research by Sarah McSweeney (pers. comm.) from University of Melbourne has revealed a strong correlation between wave height and the closing of estuaries. Sarah found that closure of estuaries was more likely to have occurred under heightened wave conditions.

While heightened wave action is considered a source of sediment that closes ICOLLs, it also drives coastal erosion processes. According to Assoc Professor David Kennedy from the University of Melbourne (David Kennedy pers. comm.), while heightened wave action may result in beach erosion and in particular the loss of material from frontal dunes, heightened wave action can also lead to the deposition of mobilised sediment into estuaries leading to their closure. Based on an assumption of heightened wave action over the period since 2011 and the information from Assoc. Professor Kennedy, we would expect to have seen an increased incidence of estuary closure since 2011.

Further work is required to better understand recent wave action at Merricks Beach over the recent past. In the absence of such information it is difficult to provide a conclusive statement on the role of recent wave action at the Merricks Creek Estuary.

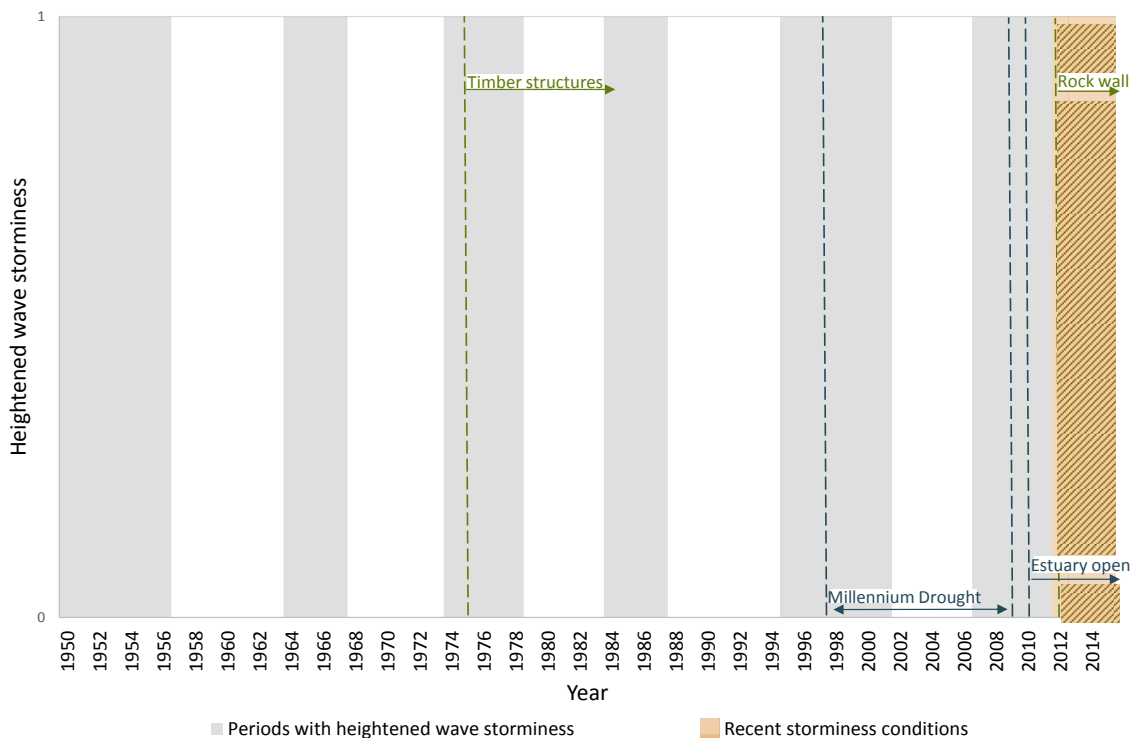


Figure 21. Storminess data 1950 to 2015. Grey shading indicates formal monitoring (source: Water Technology 2014), hatched area indicates anecdotal evidence (Christine Lachlan Arrowsmith pers comm).

Tidal processes in Westernport Bay

Westernport Bay is a protected, tide dominated bay. Westernport Bay has significantly greater tidal variation than other sites across Victoria. A comparison between Westernport Bay and Lorne is provided in Figure 22. The average tidal difference from 1994 to 2014 for Sandy Point (Crib Point) in Westernport Bay was 3.1m, compared to that of Lorne which was 2.4m.

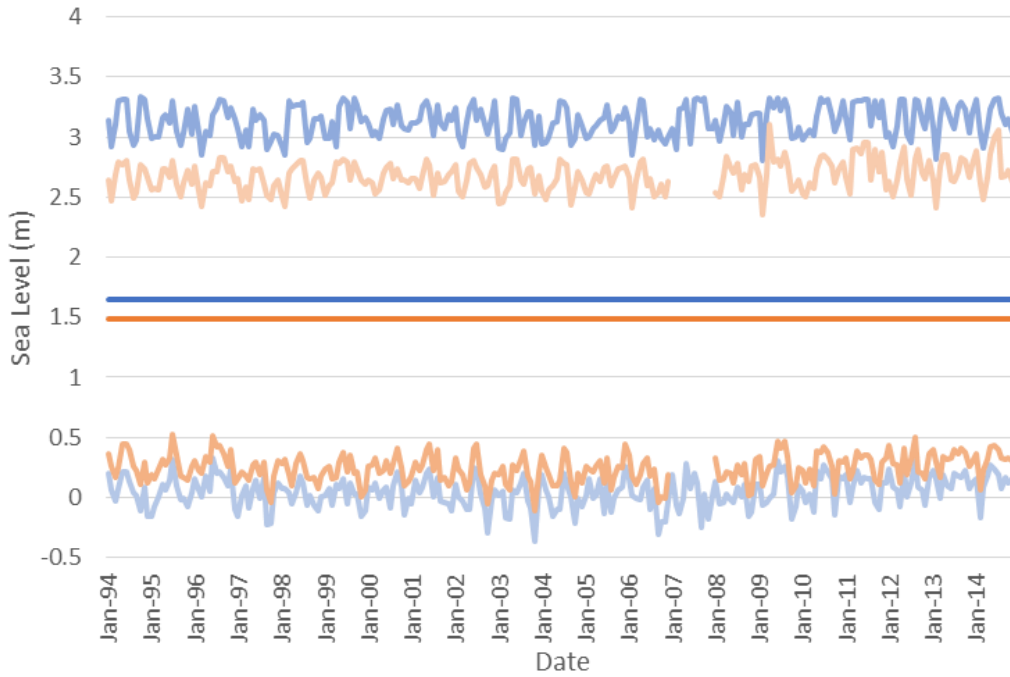


Figure 22. Tidal variations (m) over the past 20 years at Sandy Point, Westernport Bay (Blue) and Lorne (Orange). Lighter colour indicate minimum and maximum tides, bold straight lines indicate the mean average sea level across period.

The difference between flood and ebb tide flows into Westernport Bay, the Coriolis effect and wave action combine to create a net eastward current drift along the Merricks Creek foreshore area. The net current vectors around the Merricks Creek Estuary are weaker than those further to the east near Crib Point. The weak net currents around Merricks Creek Estuary result in low rates of sand movement, but allows ongoing movement of more mobile seagrass.

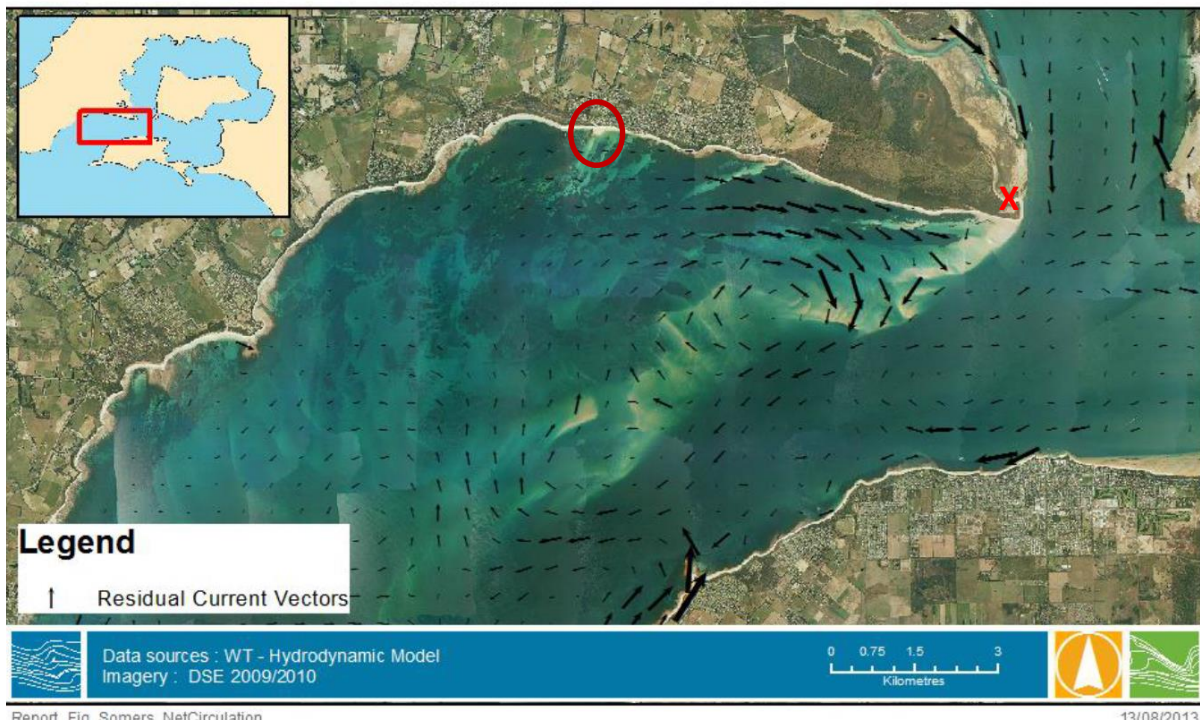


Figure 23. Residual tidal and wave current vector plot (Water Technology 2014). The Merricks Creek Estuary mouth is located within the red circle and Crib Point is marked by the red cross.

Catchment flows

Rainfall and the resulting catchment flows are an important factor in the opening and closing regime of ICOLL's.

Major flow events can lead to a breach of the bar and similarly continual high flows or wet conditions can lead to the persistence of an open estuary. Land and water use within a catchment can alter the flow regime and therefore alter the occurrence of estuary opening and closing.

Merricks Creek has relatively low stream flow. While increased urban development will increase runoff from those areas, dams associated with agricultural development may reduce peak flows, cause more evaporation but also more infiltration. The Merricks Creek catchment is described as being 'over allocated', a function of water policy in the mid to late 1900s; this over allocation is typical of most catchments in southern Victoria. We have not investigated the extent to which urbanisation has increased runoff and any offset arising from an 'over allocation' of water resources. However these influences are likely to be less significant than larger scale variation arising from climate variability.

Annual rainfall data was taken from the nearby Shoreham gauge and a 3 year moving average is derived, displayed in Figure 24. The data shows highly variable climatic conditions for both the catchment and coast have varied over the past 65 years. The station has a mean annual rainfall of 905mm (median of 915mm). Low annual rainfall was recorded during the Millennium Drought, from 1997 - 2009 (BoM 2015a), with a return to above average rainfall from 2010 to 2014. This above average rainfall was consistent with La Niña events. We are now seeing a recent return of below average rainfall.



Figure 24. Shoreham rainfall data 1950 - 2015. Mean annual rainfall over period = 905mm (Source: BoM 2015a)

The end of the Millennium Drought was marked by the start of the 2010 to 2012 La Niña event, Australia's wettest 24 month period on record. Sustained positive values of the Southern Oscillation Index (SOI) above +8 are typical of a La Niña episode and sustained negative values below -8 are typical of an El Niño. Figure 25 shows the La Niña period between 2010 and 2012 and the neutral period following. The SOI below -8 observable from 2015 onward indicates the beginning of an El Niño episode. As this strengthens, eastern Australia is expected to experience below - average winter- spring rainfall with the episode peaking at the end of the year (BoM 2015b).

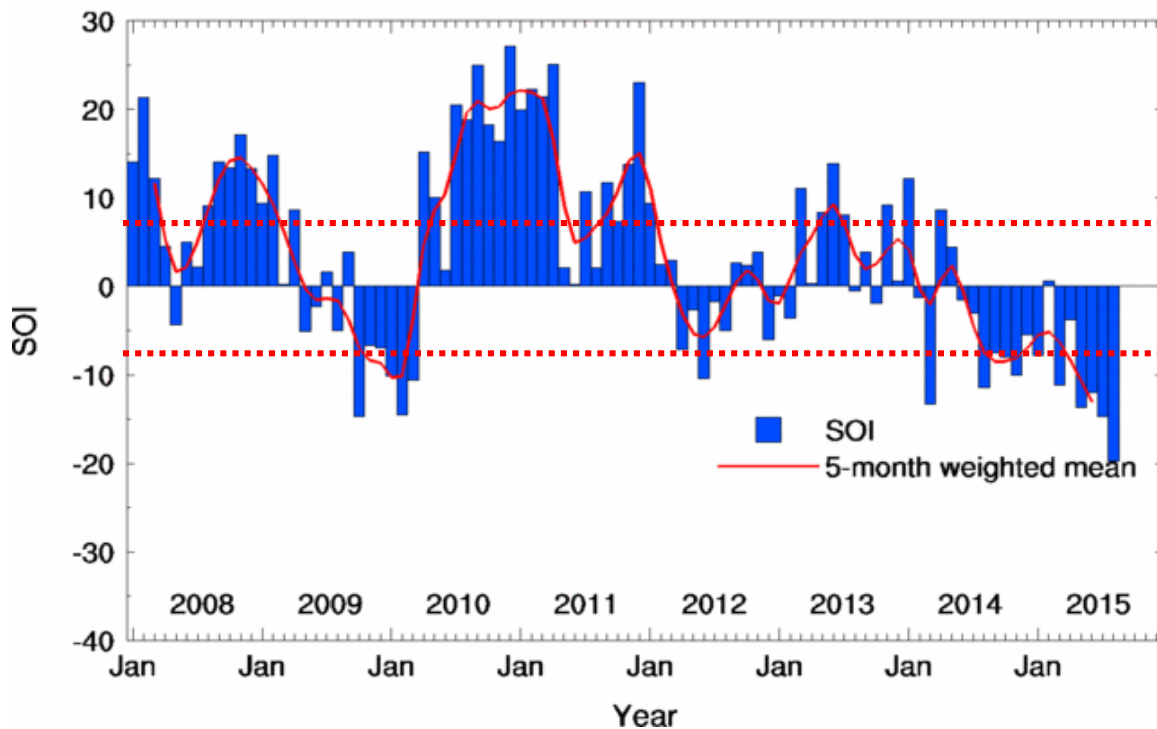


Figure 25. Southern Oscillation Index (BoM 2015b)

Impact of the rock wall

It has been hypothesised that a difference between the old timber wall built in the 1970's and the rock wall of 2011/12 could be contributing to a change in the balance of energy (erosion vs deposition) at the estuary mouth. The old timber wall that was present on the east side of the estuary contained a number of integrated lateral timber groynes. These groynes protruded into the tidal flow path and the top of the tide, provided a degree of 'roughness' to wall. Such roughness could have contributed to the absorption of energy associated with runoff events, tidal movement and wave energy, resulting in sediment deposition and accumulation in this area of the estuary mouth. The rock wall that is now present does not feature any such lateral roughness. The absence of such roughness could be resulting in flow energy being expended in local scour against this rock wall, and a reduction in the trapping of sediment resulting in a narrow and deeply incised channel that holds the estuary open.

There is some evidence of such energy expenditure against the current rock wall , specifically the persistent scoured channel located against this wall.

'based on an initial review of the aerial photography, it does appear that the channel thalweg has changed position following construction of the rockwall. The channel thalweg now runs directly alongside the wall thus increasing the scour from outflow. A similar process was observed in my work at the Gellibrand River estuary where the channel remained incised to near mean sea level and maintained high velocity outflow alongside a headland for nearly a year. The channel in this case was diverted due to a rockfall, which forced it alongside the cliff (McSweeney, Pers. Comm. 2015).

The scour path has remained in its current location, adjacent to the rock wall for the entire period since construction. This is in contrast to the location of the low flow channel during periods of estuary opening prior to the rock wall construction.

A contrary argument to this hypothesis is that the lateral timber groynes were relatively small and were only likely to have a very marginal impact on the processes at work.

Discussion

The form of an estuary and the opening and closing of wave dominated estuaries are a function of the combination of wave energy, tidal energy and the energy associated with catchment discharges (runoff). Areas

of Australia with high tidal range, large stream flows and low wave energy tend to result in tide dominated estuaries that are permanently open. These are typically found in northern Australia. Estuaries with a dominance of wave energy, over the forces of tide and stream flow tend to result in ICOLL's i.e. opening and closing estuaries). It appears that the estuaries of Westernport Bay may operate on the threshold between tide dominated estuaries and wave dominated estuaries. This is a function of the tidal range and limited wave action. Those estuaries located deeper within Westernport Bay, protected from wave action, are tide dominated estuaries. Merricks Creek Estuary while having a high tidal range has a more open aspect than the other estuaries of Westernport Bay and as a result has typically operated as a wave dominated, ICOLL.

However it appears that Merricks Creek Estuary may lie at the edge of this estuary type, with longer periods of estuary opening made possible as a result of a combination of increased rainfall, the reduced wave action, and or an increase in local tidal energy associated with the rock wall construction. Such longer periods of opening have not occurred in the recent past, because this combination of events has not occurred in the recent past.

Unfortunately, we have not been in a position to provide a definitive statement on the role of the recently constructed rock wall in contributing to the current open estuary condition. There is very limited information of waves within Westernport Bay and there are no gauge stations that measure stream flow in the creek.

Ongoing research into wave action in Westernport Bay is being undertaken by Deakin University in association with Water Technology. Results from this research are expected in 2016. This research could contribute to the resolution of this matter.

Alternatively and more immediately, further investigations could be undertaken based on the empirical research by McSweeney. McSweeney has developed a model based on empirical observations that can draw relationships between catchment runoff, wave height and tides to hindcast whether an estuary was open or closed. This empirical relationship (model of processes) could be applied to identify which of these three factors is causing the prolonged opening, or whether an additional factor (such as the rock wall) needs to be considered. Such investigations are beyond the timeframe (Water Technology) and scope (McSweeney) of this current assessment. The issue of further investigations are discussed in chapter 4 of this report.

3.2 Release of hydrogen sulfide

The persistent odour at the Merricks Creek Estuary is consistent with that of hydrogen sulfide gas (H₂S). Hydrogen sulfide is a product of the decomposition of organic matter associated with the production of acid sulfate soils. Acid sulfate soils are of national concern and are described in detail in federal government strategies (EPHC 2011 and NWPASS 2000) and state government strategies (DSE 2009) and guidelines (DSE 2010a). Figure 27 shows the location of potential coastal acid sulfate soils in the region (DPI undated).

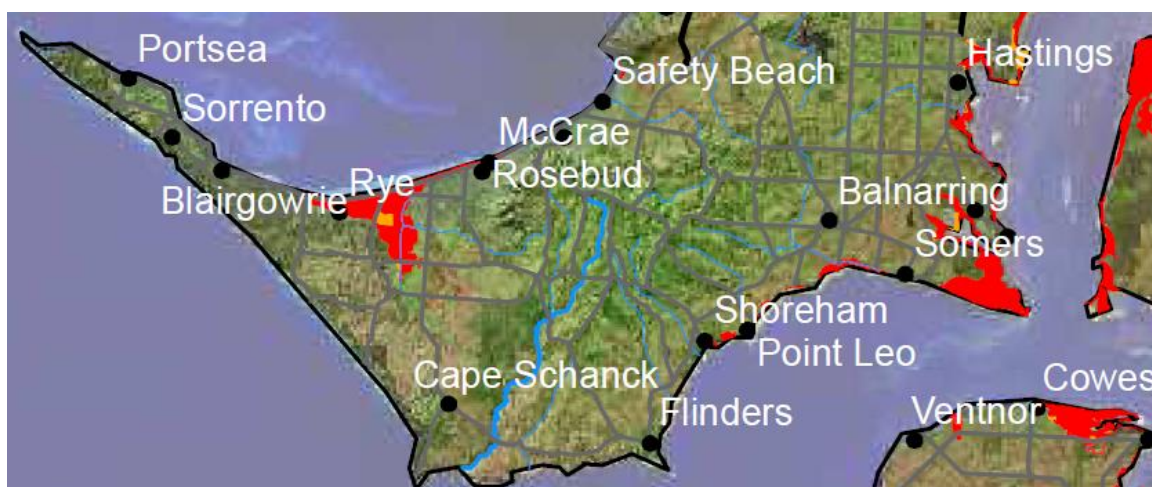


Figure 26. Prospective coastal acid sulfate soils identified through geomorphological assessment (Red areas) Source: DPI undated

Depending on the tidal conditions, hydrogen sulfide can be released through the water column when the soils are inundated (flood tide) as part of the production of acid sulfate soils, or released directly through the soils when exposed (ebb tide). The processes relevant to Merricks Creek Estuary are summarised below.

Inundated scenario

When organic matter is combined with sulfates (SO_4^{2-}), contained in sea water, under anoxic conditions, sulfate reducing bacteria decompose the organic matter and convert it to sulfide (S^{2-}). The sulfide then reacts with metal ions present in the soils (especially iron, Fe) to produce metal sulfides (the black sludge observed in the Merricks Creek Estuary) and hydrogen sulfide (H_2S). This hydrogen sulfide is released into the water column, where it is either released to the atmosphere, or will react with available oxygen to return as a sulfate precipitate (a white material that can sometimes be observed in the water column). Low dissolved oxygen levels, high organic matter loads and a sulfate supply from either sea water or groundwater will result in the formation of coastal acid sulfate soils over hundreds and thousands of years. This production process is ongoing and can occur where there is organic matter and seawater under anoxic conditions. The production of metal sulfides and release of hydrogen sulfide is described in Figure 27.

Exposed scenario

When acid sulfate soils are exposed to the atmosphere, hydrogen sulfide and other sulfidic gases produced from the anoxic reduction process, trapped within the acid sulfate soils, can be released and escape directly into the atmosphere. This process is shown in Figure 28.

In addition to the release of gasses, the exposure of acid sulfate soils can also result in the formation and release of acid. Acid can form as a result of the oxidation of the metal sulfides (hence the term acid sulphate soils). The oxidation process creates material ready for release into the water column. This is the cause of concern in many areas of coastal Australia.

Interestingly, significant acid events have not been recorded in the Merricks Creek Estuary. It is likely that such events have been prevented by the buffering effect of the sea water entering the system each tidal cycle. Significant risk of an acid event would arise in the Merricks Creek Estuary in periods of estuary closure and very low stream flow followed by a small rainfall event. The low flow rate could result in the exposure and oxidation of the acid sulfate soils. A subsequent small rainfall event could then result in the release of the oxidised material / acid into the water column, with insufficient flow to either dilute the acid or breach the estuary.

Discussion

It is most likely that the odour occurring at Merricks Creek Estuary is resulting from the H_2S released from both the anoxic decomposition of contemporary organic material when inundated and the release of H_2S during low tide. Fundamental to the anoxic decomposition process is a source of contemporary organic material.

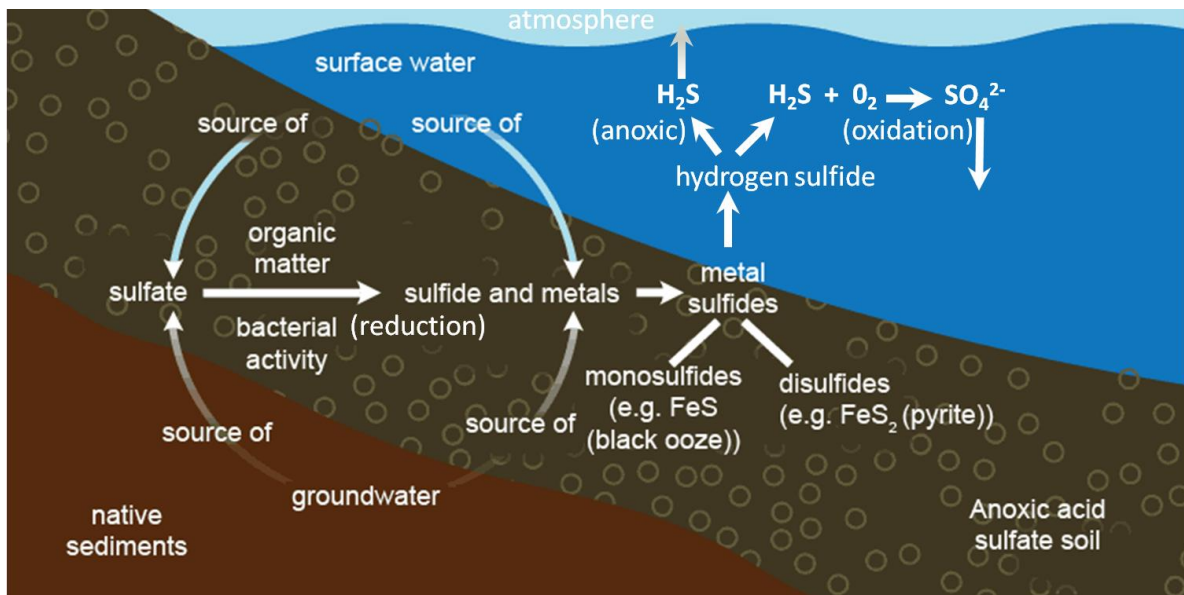


Figure 27. Sulfate reduction occurs when organic material is decomposed in anoxic conditions, releasing hydrogen sulfide into the atmosphere (source: adapted from EPHC 2011).

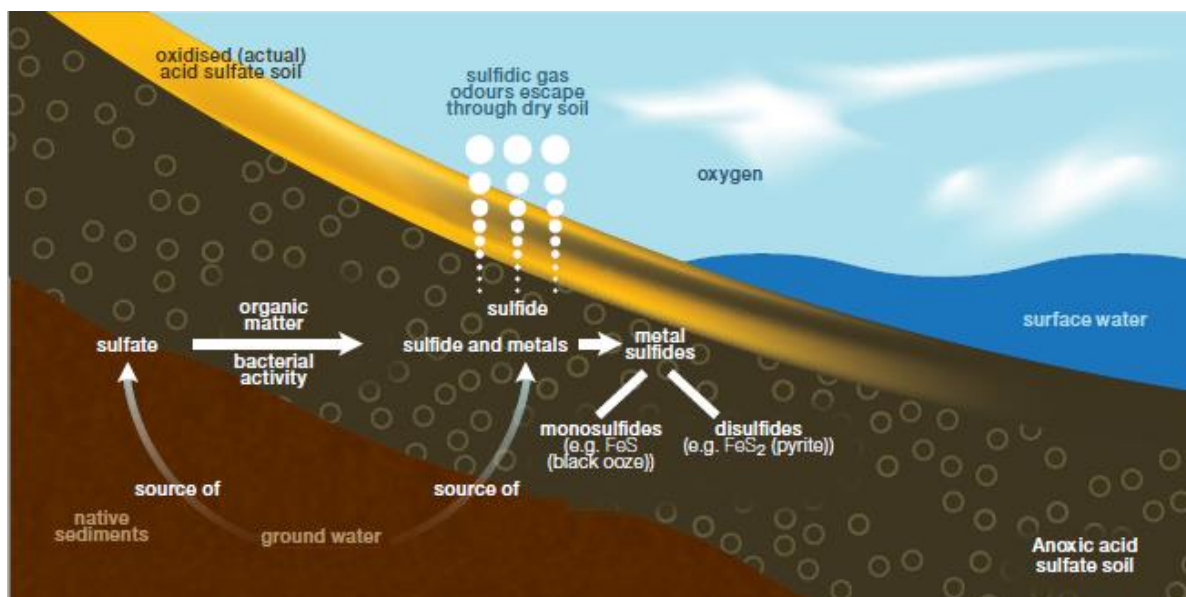


Figure 28. Exposure and release of sulfide in a drying scenario (source: EPHC 2011).

While the production of hydrogen sulfide is a natural process, there are some risks. These risks and the implications for the Merricks Creek Estuary are discussed in Chapter 4 of this report.

3.3 Organic material in the estuary

The presence of organic material in the estuary is a key factor in the sulfate reactions. This section explores three main sources of organic material in the estuary:

- Sea grass transported into the estuary (current process)
- Catchment generated organic material (current process)
- Existing deposits of organic material.

Sea grass transport into estuary

Abundant sea grass deposits have been observed in the estuary and also on Balnarring Beach, west of the estuary mouth (Figure 29 and Figure 30). Sea grass is deposited on the Balnarring beach and transported in a net eastward direction as a result of the coastal process, namely:

- circular current patterns in this location of Westernport Bay
- swell waves from a south westerly direction
- longshore drift. While significant longshore drift of sand has not been observed, sea grass is more easily transported and has been observed to move eastward along the beach.



Figure 29. Sea grass deposits at mouth, looking west to Balnarring Beach



Figure 30. Aerial view of sea grass deposits on Balnarring Beach (September 2012) Sea grass is observed as the dark colour on the beach

Our analysis of aerial photography over recent years (2006 - 2015) (refer Attachment B) undertaken for this investigation suggests that the sea grass generally builds up on the beach in August-September, and sometimes begins as early as May.

Once moved via long-shore drift to the estuary mouth, sea grass is available to be transported into the estuary through reach 1 with tidal movements. Such transport into the estuary is dependent on the estuary being open. Once in the estuary the sea grass can then be transported into and deposited throughout reach 2 where there is lower wave and tidal energy.

This process of sea grass influx to the estuary may have been exacerbated by heightened storminess.

Once deposited in the estuary, the seagrass decomposes. The rate of decomposition in Merricks Creek is dependent on a number of geo-chemical variables including the season and the volume of the seagrass, and is expected to be in the order of months. One study measured the decomposition of a seagrass species in France (Bourges et al 1996) and found that in laboratory conditions, it took 55 days for the seagrass to decompose to ~50% of dry weight. This rate was expected to increase in situ, especially during summer months. This was corroborated by Cook (pers. comms 2015) who stated that if the Merricks Creek Estuary was to close in September/November 2015, the remaining seagrass within the estuary would likely break down over the summer period, with decomposition rates slowing again in Autumn.

Catchment influences

Organic material and nutrients are supplied to the estuary from a number of catchment processes:

- Upstream erosion of alluvial sediments
- Stormwater runoff
- Agricultural runoff
- Treated wastewater / Septic tank leakage.

These catchment influences contribute to the current poor water quality of the system. These sources are high in nutrients and are likely to also contribute to algal blooms and low dissolved oxygen events.

However based on our observations of the Merricks Creek Estuary, and the processes at work, the catchment derived sources of organic material are likely to be insignificant compared to the recent accumulations and abundance of sea grass in the system.

Existing organic material deposits

There has been a significant supply of legacy organic matter into the estuary. This is a result of past catchment sea grass input over many thousands of years to more recent influences, in particular treated wastewater.

Until the early 2000s, the main form of sewage management was septic tanks and a small treatment plant at Lord Somers Camp that discharged directly to the waterway. The waste water discharge and leakage from septic tanks would have introduced organic material and nutrients into the system, leading to the current poor water quality of the system.

However, legacy organic material is unlikely to be driving the current decomposition and odour production processes. According to Cook (pers. comm.) such legacy material has most likely already decomposed. Hydrogen sulfide derived from this decomposed material may be a component of the gas emissions during the drying phase (low tide). However legacy material is unlikely to contribute to new gas production.

Analysis and discussion

To assist with this investigation we have assessed the relative contributions of organic material supplied to the estuary from seagrass, legacy sewage treatment discharge and current stormwater and urban runoff. We identified the likely inputs of sea grass based on the extent of current sea grass deposits observed within the estuary and an assumption that sea grass entering the system each year would fully decompose in that year. Loads from sewerage discharge, stormwater and rural runoff have been based on standard parameters for these pollutant loads. The factor that can be most readily compared between these sources is nitrogen. We estimate the nitrogen load from the sea grass within the estuary was order(s) of magnitude greater than the loads derived from other sources (refer Figure 31). Attachment C details the calculations used to determine catchment loads.

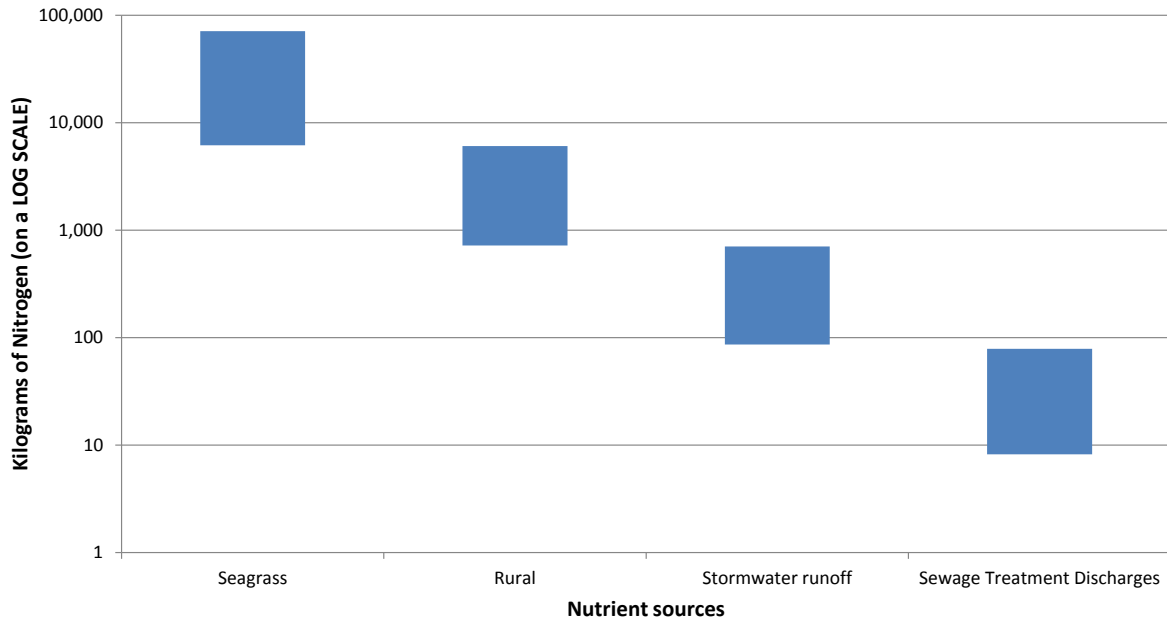


Figure 31 Relative loads of nutrients into Merricks Creek Estuary (Note this is a log scale)

Based on the information available, we are of the opinion that the organic material driving the production of hydrogen sulfide is the sea grass accumulations in the estuary. Sea grass influx and accumulations within the estuary have increased as a result of the extended period of the open estuary condition from 2010 to 2015.

3.4 Water quality in the estuary

Dissolved oxygen

The dissolved oxygen and pH data for Reach 2 of Merricks Creek upstream of the estuary show isolated incidents of low dissolved oxygen and generally neutral or slightly alkaline water conditions.

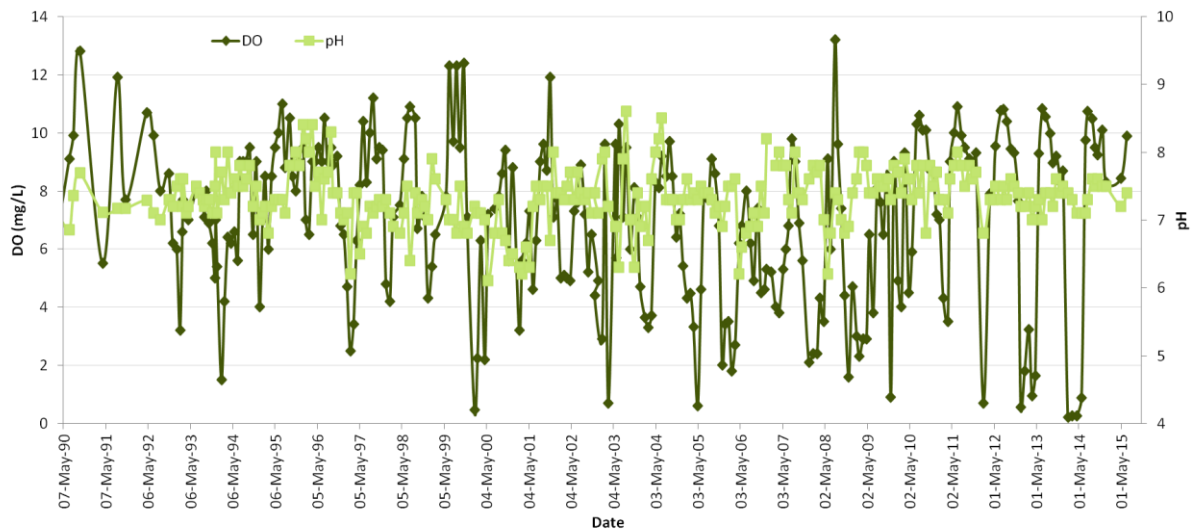


Figure 32. Dissolved Oxygen and pH in Merricks Creek at Balnarring Bridge Road - reach 2 (Source: Estuary Watch)

Low dissolved oxygen levels in estuaries can have several adverse consequences. Low dissolved oxygen levels can cause fish kills. Low dissolved oxygen levels is also a factor in the release of hydrogen sulfide through the anoxic decomposition of organic matter.

Dissolved oxygen consumption and production are influenced by plant and algal biomass, light intensity and water temperature (because they influence photosynthesis), and are subject to diurnal and seasonal variation (Connell & Miller 1984). Stratification due to a layer of saline water not mixing with freshwater can also cause low dissolved oxygen events in the bottom waters.

Low dissolved oxygen events are more likely when estuaries are closed to the ocean. Under these conditions, the water backs up behind the sand berm and can become stagnant. High nutrient loads and warm weather can exacerbate these events.

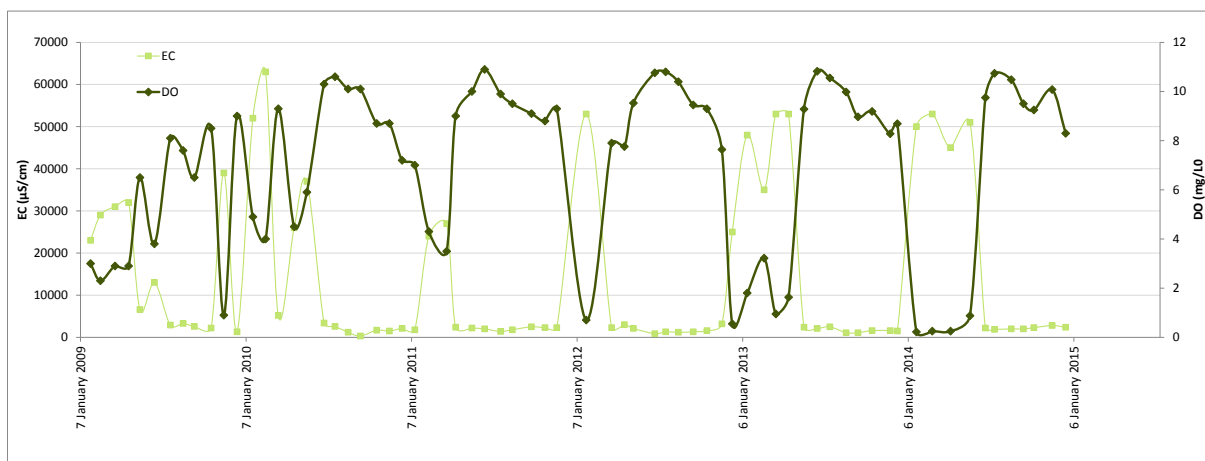


Figure 33. Dissolved Oxygen and EC in Merricks Creek at Balnarring Bridge Road - reach 2 (Source: Estuary Watch)

Low dissolved oxygen levels can result in fish kills. There have been frequent fish kill events in the Merricks Creek Estuary prior to the recent period of open estuary conditions. It is also understood that a fish kill occurred in 2015. These fish kill events could have been associated with:

- algal blooms and associated reductions in dissolved oxygen
- low dissolved oxygen associated with conversion of hydrogen sulfide gas to sulfate in the water column
- acid events.

Salinity

The salinity levels in reach 2 of the Merricks Creek Estuary are provided in Figure 34. Seasonal variations in salinity reflect the relationship between catchment flows and sea water intrusion, with the troughs representing periods when the fresher catchment flows dominate the reach.

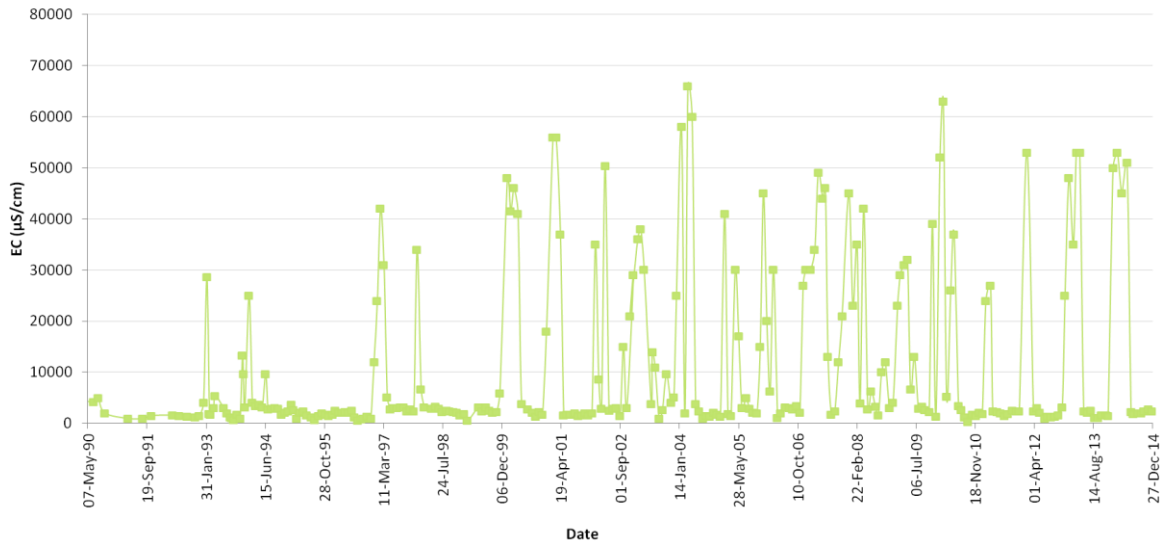


Figure 34: Salinity (EC) in Merricks Creek at Balnarring Bridge Road - reach 2 (Source: Estuary Watch)

3.5 Water depth

Two processes are likely to have influenced water depth and the potential for recreational boating in the estuary.

1. **Input of sand:** Sand has been observed to have covered rocks in the bed of the estuary in reach 1. Sand is likely to have been transported into the estuary through a process known as tidal pumping. This process occurs as a result of the open estuary condition and daily tidal movements. While the daily rate of sand transport through this process is likely to be low, the persistence of the process over the past 5 years could account for the observed build-up of material.

The build up of sand in reach 1 is evident in recent images of the estuary (refer Figure 35).



Figure 35 2009 and 2014 aerial images showing sand accumulation in Reach 1

2. **The tidal variability:** Daily tidal variations result in low water levels in the estuary twice every 24 hours. This low water level will also contribute to the observed shallow water conditions in the estuary and would contrast to the near permanent high water level in the estuary during periods of estuary closure.

We suggest that the observed shallowing of the estuary is a function of both the influx of sand and the daily tidal variation within the estuary.

3.6 Discussion

Merricks Creek Estuary is an ICOLL that has become open for an extended period of time. The opening and closing regime of ICOLLS are the result of tidal, wave and inflow forces. Defining which of these forces has driven the continued opening of the estuary is challenging.

We have found the Merricks Creek estuary to be unusual and may lie at the edge of a wave dominated ICOLL. The estuary has tidal range consistent with a tidal estuary, but sufficient wave action to result in the wave domination and closure. We have insufficient information to identify the nature of the waves over the past 5 years and therefore not in a position to identify whether the natural processes alone account for the extended period of estuary opening, or whether an additional factor (e.g. the rock wall) is necessary to account for the extended opening. We found the current rock wall has less roughness and less capacity to trap sediment and as a consequence may be less able to dissipate tidal energy and as a result contributed to the extended opening. Some additional investigations would be required to identify the extent to which the rock wall has contributed to the extended period of estuary opening.

Despite this uncertainty there is clarity around the impact of the extended period of estuary opening which has resulted in:

- sea grass influx to and accumulation within the estuary. This influx and accumulation has driven a sulfate reduction process under anoxic conditions and the production of hydrogen sulfide and the creation of monosulfides (black sludge). This process and the subsequent low tides result in the release of hydrogen sulfide. The release of gas can occur under both the wet high tide conditions and damp low tide conditions. In addition the low tide conditions can provide for the oxidation of monosulfides and the release of additional sulfidic gasses.
- the estuary becoming increasingly tidal, resulting in the tidal pumping of sand into the estuary and the daily lowering of water levels associated with low tide. These have contributed to the establishment of low water depths that have limited recreational boating (rowing and paddling).

It is unlikely that catchment based sources of organic matter are the dominant cause of the recent persistent odour in the estuary. Such sources would have resulted in persistent odours prior to the current issues arising. This is not to suggest that organic matter from the catchment is not a problem. Such catchment based sources are likely to be the dominant source of new organic material to the estuary once it is closed, contributing to algal blooms, associated low dissolved oxygen conditions and fish kills.

4 Objectives and options

4.1 Objectives

This investigation has been undertaken to address three primary issues of concern to the community:

- Persistent odour
- Fish kills, and
- Shallowing of the estuary

Based on the dominant processes understood to be occurring in the system, we have developed four broad objectives for the management of the estuary to address these concerns.

- Reduce organic loads supplied to the estuary
- Maintain high levels of dissolved oxygen in the estuary
- Avoid disturbance and exposure of the existing monosulfides in the estuary
- Increase depth of water in estuary

These objectives provide complementary and potentially conflicting means of achieving the desired outcomes.

Table 3. Objectives for attainment of desired outcomes

No.	Broad scale options	Description
A	Reduce organic loads supplied to the estuary	<i>Aims to prevent sulfate reduction process</i> <ul style="list-style-type: none">• Reduce the amount of organic material in the estuary.• Includes both existing material and current influx of sea grass• Focus is on sea grass rather than catchment loads
B	Maintain high levels of dissolved oxygen in the estuary	<i>Aims to prevent algal blooms and limit sulfate reduction process</i> <ul style="list-style-type: none">• Reduce organic loads to the estuary (refer above)• Avoid extended closure of estuary mouth• Manage organic inflows
C	Avoid disturbance and exposure of the existing monosulfides in the estuary	<i>Aims to prevent sulfide oxidation process</i> <ul style="list-style-type: none">• Do not disturb the current deposits of monosulfides (black sludge)• Where possible, inundate monosulfides to prevent oxidation and to prevent release of H₂S stored / trapped in the monosulfides (note that this may conflict with Objective B)
D	Increase water depth in estuary	<i>Aims to increase depth of water in estuary for recreation outcomes</i> <ul style="list-style-type: none">• Where possible, raise water level in estuary through more frequent closure to improve recreation opportunities (May conflict with Objective B)• Prevent tidal pumping of sand into estuary

4.2 Identification and assessment of options

Potential options that could be implemented to achieve these objectives have been developed through consultation with the community working group and through discussions with a panel of technical specialists. Three main groups of actions were identified and assessed:

- Group 1: focus on reducing the organic material loads in the estuary
- Group 2: focus on ways to manage dissolved oxygen in the estuary
- Group 3: focus on the estuary opening and closing regime.

Table 4 provides a qualitative assessment of the likelihood that each potential management group of actions will provide a beneficial influence on the proposed objectives (Table 3) and therefore contribute to the attainment of the desired outcomes. This table also identifies any potential negative influence on the objectives. These options are discussed below.

Table 4. To what extent do alternative options meet the objectives?

Options		Objectives			
		A. Reduce organic loads in and delivered to estuary	B. Maintain high dissolved oxygen levels in estuary	C. Avoid disturbance and exposure of monosulfides	D. Improve water depth for recreational boating
1a	Remove recent seaweed accumulations from estuary	✓✓✓	✓✓✓	x	✓
1b	Remove seagrass from beach (west of estuary) before it enters nestuary	✓✓✓	✓✓✓	-	✓
1c	Prevent sea weed from entering estuary	✓✓✓	✓✓✓	-	✓
1d	Reduce organic inputs from catchment	✓✓	✓✓	-	-
2a	Increase catchment flows (manage extractions / dams)	✓	✓	✓	-
2b	Introduce an additional oxygenated source of water (add potable / other water source)	✓	x	✓	-
2c	Oxygenate water in estuary (bubblers, splashers)	-	✓✓✓	-	-
2d	Pump sea water into estuary	-	✓✓	✓	✓
3a	Do nothing: allow natural build-up of sand berm to achieve the closure	✓	x	✓✓	✓
3b	Encourage natural closure: Install roughness (resistance) along rock wall	✓	x	✓✓	✓✓
3c	Manually close - use earthmoving machinery	✓	x	✓✓	✓✓
3d	Permanently close- Construct a weir across estuary	✓	x	✓✓	✓✓
3e	Semi-permanent structure- manually manage open and closure.	✓	✓	x	✓
3f	Permanently open - Install rock wall and remove sand	x	✓	✓✓	x

Group 1: Reduce organic loads

These options, aimed directly at the supply of organic loads to the estuary, will have the greatest direct impact on hydrogen sulfide production and will also have the potential to reduce oxygen demand and hence oxygen levels in the estuary. However each of these direct interventions have some limitations.

Reducing catchment loads is rated as medium influence as this source only contributes a small proportional amount of organic material when compared against the current influx of seagrass. Most works to reduce organic loads from the catchment will have a long lead time before benefits are observed. Nonetheless this option will be essential to address longer term organic loads in the estuary during periods in which the estuary is closed.

Removing recent seagrass accumulations from the estuary has the potential to have an immediate positive impact on hydrogen sulfide production. However, the process of removing the sea grass is likely to result in significant short term problems. Currently the sea grass is vertically layered through reach 2 of the estuary. The upper layers are comprised of material recently transported to the estuary. Lower layers are in varying degrees of decomposition. Removal of the upper layers is likely to result in the mobilisation of the underlying lower layers and associated disturbance to the monosulfides.

On initial review the **physical removal of seagrass from Balnarring Beach** appears to have merit. The work could be undertaken relatively simply via a front end loader and truck operation. The removal of this material from the beach would prevent its transport to the estuary mouth and subsequent transport into the estuary. Removal of sea grass and kelp from beaches is not without precedent. We understand that similar activities have been undertaken on the Mornington peninsula in the past. One local resident recalled kelp removal from nearby Shoreham beach being undertaken in the late 2000's. We have not been in a position to confirm such removal with Mornington Shire Council. We also understand that Council undertook some sea grass removal from Flinders beach to address a local public health risk. However, there are significant risks associated with such programs of sea grass removal. The Balnarring Beach and other beaches in the area provide habitat for Hooded Plover, known to feed among sea grass and nest above the shoreline. The hooded plover breeding season starts in summer, shortly after the period when the seagrass was observed to start accumulating. Heavy machinery used to remove sea grass and the physical removal of sea grass would pose a risk to the hooded plover and its nesting.

There is potential to explore options that seek to trap, collect and **remove sea grass from within reach 1** of the estuary, before it is transported, stored and commences decomposition within reach 2. These options could include construction of nets or temporary barriers through reach 1. These structures would require regular maintenance to both ensure their structural integrity and to remove the accumulating sea grass. There is a complexity in the design and operation of such works. The works could be built with a low level of robustness e.g. temporary netting and thereby not impact on estuary opening and closing process. This arrangement would necessitate regular repair and maintenance. Alternatively, the structures could be more robust, in which case they may have an unintended impact on the opening and closing regime of the estuary. This issue is discussed under the opening and closing regime for the estuary.

Options that seek to close the estuary as a means of reducing the sea grass entry, are discussed under the final group of options.

Group 2: Manage dissolved oxygen

These options comprise those interventions that directly influence the oxygen levels within the estuary. The options would seek to prevent the anoxic decomposition of organic matter that has been transported to the estuary. The maintenance of high levels of oxygen in the water column could also assist prevention of sulfide gas release and prevent fish kills arising. However, these options will only have any significant influence once the estuary is closed, and is no longer receiving twice daily inputs of sea water

Managing dams and water extractions could assist to maintain turnover of water in the estuary when the estuary is closed, at times of low flows. However, the influence that could be achieved through this option is only marginal and would not guarantee the levels of oxygen necessary to prevent anoxic decomposition of organic material. This option alone would not achieve the intended outcomes.

The introduction of an additional water source could also assist to maintain turnover of water in the estuary. Water sources could include pumped sea water and the introduction of recycled water. The introduction of additional sea water would contribute sulfidic material to the estuary and hence would contribute to the production of hydrogen sulfide. This option should not be pursued. The introduction of recycled water could be of assistance. However such water would need to be low in nutrient content. This may not be possible with recycled water.

Alternative means of introducing oxygen into the water column include aerators such as pumping air into the estuary via a porous hose laid along the creek bed. Other aerators could include a means to mechanically disturb the water surface. While possible, these options are not considered practicable.

Group 3: Manage estuary closing regime

The third group of options look at ways of managing the estuary mouth. Options include encouragement and management of an open estuary, the encouragement and management of a closed estuary, and management of an opening and closing estuary.

Catchment based organic material could be more readily removed from the estuary by **encouraging and maintaining an open estuary**. Such an arrangement would comprise a more permanent establishment of the current conditions. The arrangement would reduce the occurrence of algal blooms and associated fish kills. This is an arrangement that is adopted to improve water quality in many estuaries across eastern Australia. However the open estuary does not address the influx of sea grass at Merricks Creek Estuary and would require the establishment of an ongoing program of sea grass collection and removal. The option would not address the shallowing of the estuary and the impact on recreational boating and would require the establishment of an ongoing program of dredging.

Encouraging the closure of the estuary would prevent the influx of sea grass and assist to maintain the inundation of the existing mono sulfides. This option would cease the production and release of the hydrogen sulfide. This option would also reduce the influx of sand and the tidal influence on water level in the lower reaches of the creek providing increased water depth for recreation. Works that could be installed and undertaken to achieve a more permanent closure could include full and partial structures across the mouth of the estuary and or across other sections of the estuary.

However, the closure of the estuary would not provide the benefits of an open estuary and in particular would not provide for the flushing of material, necessary to reduce the incidence of algal blooms. Tidal flushing occurs only with an open estuary and assists to provide high dissolved oxygen. Of particular concern would be the installation of works that reduced the likelihood of natural breaches, essential for the flushing of organic matter from the estuary. Installation of structures that reduced the occurrence of natural openings of the estuary were not favoured by the expert panel

Other options include:

- **Do nothing:** The 'do nothing' option trusts that the estuary returns to a suitable opening and closing regime. The do nothing option is largely based on an assumption that while the estuary is experiencing an extended period of openness, this will come to an end and the natural process will close the estuary again in the future. However, a return to an opening and closing regime of the past may not meet the agreed outcomes.
- **Install limited roughness to rock wall:** The installation of some limited roughness to the rock wall, to replicate the system prior to the rock wall construction. Similar to the above, such a return to pre existing conditions may not meet longer term outcomes.
- **An interventionist opening and closing:** The establishment of a more interventionist opening and closing regime for the estuary would seek to encourage closure of the estuary at the time that sea grass is accumulating on Balnarring beach and being transported by longshore drift past the estuary mouth. The option would seek to encourage an estuary opening if there were signs of an impending blue green algal event. Such an approach would rely on higher levels of monitoring and system management than are currently applied.

4.3 Discussion and preferred strategy

It has become clear that there is not a simple solution to address the processes and achieve the desired outcomes for the Merricks Creek Estuary.

Primarily we propose a solution that achieves a reduction in sea grass influx, through closure of the estuary mouth. Closure in the winter and spring periods provides the greatest chance of reducing the influx of sea grass. However we do not propose major works that would significantly impact on the breach of the estuary in major flow events. Longer term nutrient management is proposed as a means to reduce long term intervention in the management of the estuary.

While there is uncertainty over the cause of the current extended opening of the estuary, it is clear that the current open conditions fail to meet community expectations. We propose both short and medium term measures to manage the system. These measures are set out below and in Figure 36.

Short term (next 1 to 12 months)

In the short term we propose two alternate options to manage the processes at work.

Option 1: The first option comprises the implementation of interim works, monitoring of outcomes, further investigations and ongoing communications with the community and stakeholders.

Short term works: **We propose that a series of small scale, low key interventions be undertaken to achieve estuary closure and halt the influx of sea grass to the estuary through October and November 2015. It is proposed that these works comprise installation of interim sand groynes that protrude laterally from the recently constructed rock wall. It is proposed that the lateral sand groynes be placed in similar location to the timber groynes that protruded from the previous timber structure. The purpose of these works would be to achieve closure. The costs of these works and a limited selection of potential other works is provided in**

- Table 6. The layout of the proposed works is shown in Figure 37. Note these works have not been assessed by DELWP and will require some refinement and co-ordination prior to implementation. Alternate interim works have been considered but dismissed based on the practicalities and constraints associated with the limited time available for installation. These works are not required beyond the period that the current large volume of sea grass is present on Balnarring Beach. We therefore do not need the works to survive beyond a four to 8 week period, up to Mid December 2015.
- **Short term investigations:** It is expected that the estuary closes, either as a result of natural processes and or the small scale interim works. However it will not be immediately clear, whether the closure can be attributed to the interim works. It is proposed that investigations be undertaken, using the techniques developed by University of Melbourne (McSweeney) to establish whether the current period of extended estuary opening can be attributed to the past rainfall and wave conditions, or whether an additional factor (e.g. the rock wall) is required to explain the openness. Similarly the analysis could be subsequently used to assess whether any closure of the system after the installation of the interim works can be attributed to the wave and rainfall, or whether an additional factor is required to explain the closed conditions.
- **Short term monitoring:** A monitoring and evaluation program will be required over the forthcoming summer season to monitor estuary opening and closing and estuary water quality.
- **Short term communications:** A communications strategy will be required to ensure the community is aware of the short term program objectives and the next steps for management of the system.

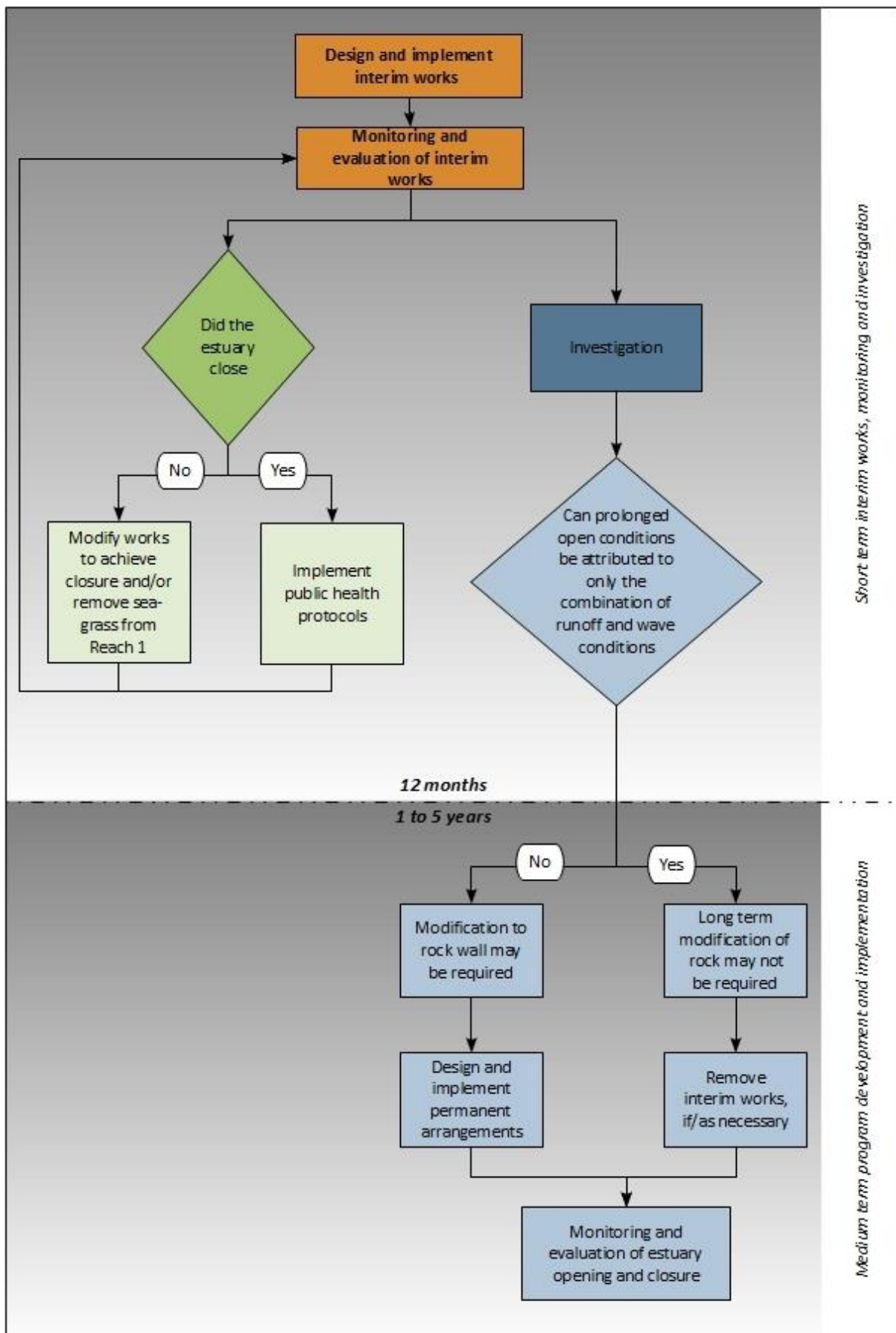


Figure 36 Short term and medium term program flow diagram

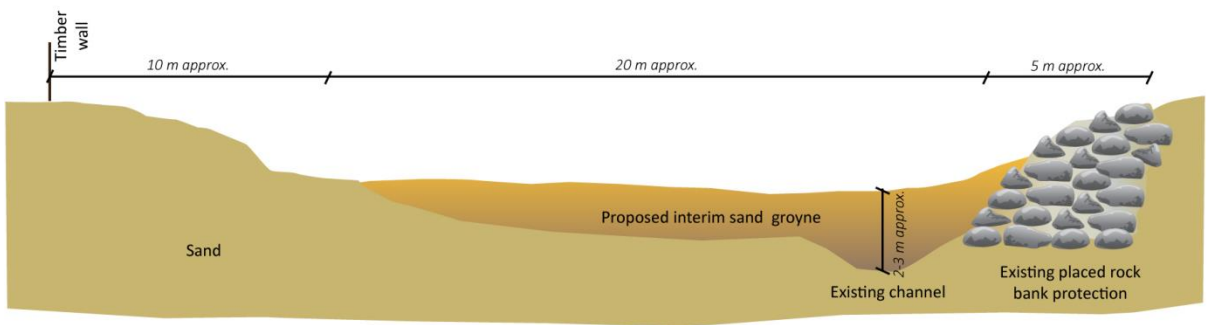


Figure 37 Proposed interim works comprising lateral sand bag / rock groynes replicating previous timber groynes

Implications of proposed short term program

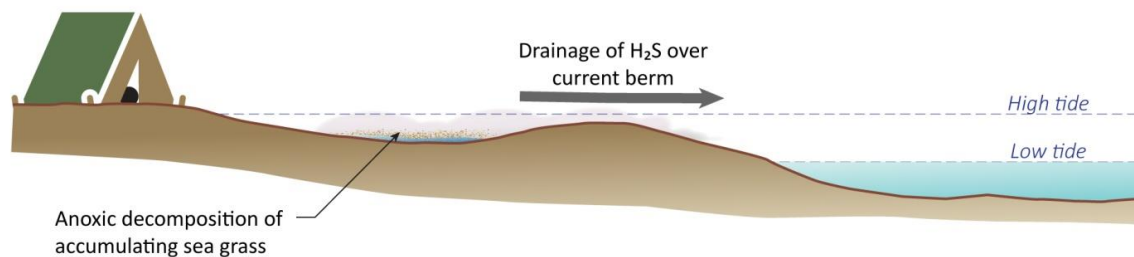
There are a number of immediate implications that arise from the proposed pathway forward. These include adverse water quality outcomes, ongoing hydrogen gas production and the potential for camp site and other inundation

Adverse water quality outcomes: We expect some adverse water quality outcomes this coming summer as a result of both the current organic loads and a closed estuary. The high organic loads could lead to algal blooms and or fish kills.

Hydrogen gas production: The proposed short term works will not remove the current load of sea grass contained in the estuary, which will continue to decompose and produce hydrogen sulphide. While the works are expected to assist closure of the estuary and cease the influx of additional sea grass, we expect ongoing gas production until the existing material has decomposed. Investigations have revealed that the sea grass will have a half life of approximately 50 days. We would expect that the estuary will continue to produce hydrogen sulfide over the forthcoming summer (2015/16). The majority (90%) of the existing sea grass load should be decomposed within 150 days once supply has been cut.

In addition to the unpleasant odour, the hydrogen sulfide production can pose some risk to human health that is worth discussion and assessment. Hydrogen sulfide gas is more dense than air and as a result can settle within depressions. There is potential for such gas to settle in extremely calm conditions (e.g. overnight), within the 'pool' created by and upstream of the sand berm that closes the estuary. This potential is illustrated in Figure 38.

Current conditions - open estuary



Potential conditions - following estuary closure

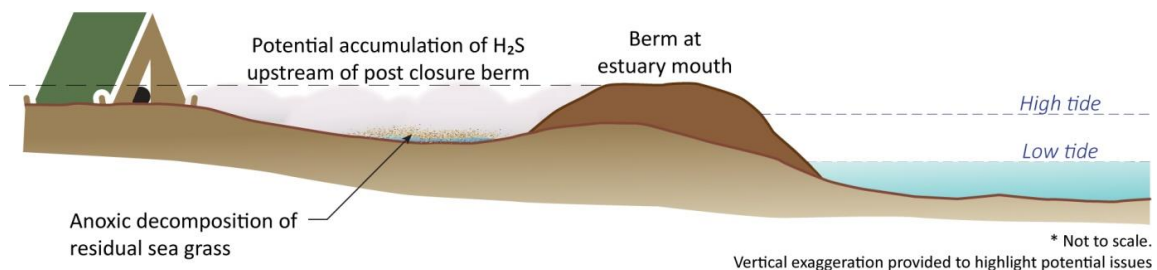


Figure 38. Potential for hydrogen sulfide accumulation following estuary closure

Risks of hydrogen sulfide poisoning would be present for those sleeping in camp grounds at elevations below that of the sand berm at the estuary mouth i.e. those camped adjacent to the estuary. Toxicity levels for hydrogen sulfide and effects on human health are shown in Table 5. We have not estimated the rate of gas production and cannot quantify this risk. This risk has not been present to date as any gas produced can 'drain' out through the current open estuary mouth. This risk should be a matter of further investigation and appropriate mitigation measures developed to reduce risks. Mitigation measures that could be provided, to reduce the risks associated with hydrogen sulfide gas production, could include air quality monitoring and evaluation, establishment of emergency protocols, temporary (short term) opening of the estuary over the forthcoming summer holiday season and / or closure of the lowest lying areas of the campground.

Table 5: Toxicity levels of Hydrogen Sulfide (H₂S) and effects to human health (Source: OHSONline.com 2007)

Concentration ranges (ppm)	Symptoms
0.005	Odour threshold
0-30	Rotten egg odour, Irritation of eyes, nose and throat
10-50	Headache, dizziness, nausea, vomiting, coughing, difficulty breathing
30-100	Sweet odour, eye damage
100+	Olfactory paralysis (loss of sense of smell)
50- 200	Sever respiratory tract irritation, eye irritation/ acute conjunctivitis, shock, convulsions, coma and death in severe cases.
300	Immediately dangerous to life
320 – 530	Respiratory failure and possibly death
800	Lethal concentration for 50% of humans for 5 minutes of exposure (LC50)
1000+	Loss of breathing and collapse after a single breath

Inundation: Closure of the estuary is likely to reintroduce past issues such as local adverse inundation of assets such as camp grounds. Protocols and agreements will need to be developed to ensure appropriate management of the estuary to prevent the adverse impacts of inundation.

We propose that these risks and in particular the risks associated with potential adverse water quality and public health outcomes be managed through the removal of the works and the opening of the estuary this summer, following the natural movement of the existing sea grass accumulations from Balnarring Beach.

Option 2: As an alternative option, and to avoid the risks with closure this summer, works could be delayed, and preparations proceed for the implementation of medium term works commencing in autumn 2016.

Medium and longer term (Autumn 2016 to 2020)

In the medium term work will be required to build upon the knowledge gained from the interim works, monitoring program and investigations. Many and varied outcomes could arise from the short term program. A flow diagram has been developed to illustrate potential actions and options. Regardless of the outcome of the short term works and investigations, it is expected that a program of work will be required to reduce catchment based organic loads to the estuary. In addition and based on the outcomes of the short term works and investigations additional works could include:

- the design and construction of more permanent lateral groynes and or installation of more permanent roughness adjacent to the rock wall
- the development of agreed estuary opening and closing protocols and responsibilities
- the development of a long term monitoring and evaluation program
- the development of a longer term communications strategy.
- The development and implementation of a longer term catchment management program to reduce catchment based nutrient loads to the estuary.

Table 6. Assessment of options

Options	Benefits and dis-benefits	Desired outcomes and potential influence	Conceptual arrangement	Cost	Feasible?	Maintenance	Sustainable?
1a Remove recent sea grass accumulations	Directly addresses organic load in estuary Disturbs creek bed. Drop in water quality during process	Odour: Yes could reduce odour Fish kills: May create fish kills in the implementation phase, may not address issue in the longer term Recreational boating: Will not address shallowing	Mechanised rake operation / aquatic weed harvesters from shallow boat. Or by hand. Perform when mouth is open, and during cooler months Pump salt water into estuary during this process to limit water quality impacts	\$50,000 to \$250,000/yr Can only work at high tide, limited visibility, high disposal costs. Limited outcomes – may not result in measurable improvement and could potentially make things worse.	Some issues Likely that monosulfides (black sludge) is integral with decomposing sea grass. Likely won't be able to distinguish these in harvesting.	Constant	No
1c Prevent sea grass from entering estuary	Only addresses sea grass that enters estuary Would need to avoid structure forming a dam-like wall Would need to avoid trapping sand and closing mouth	Odour: Yes will prevent odour if successful Fish kills: Will not reduce long term impacts associated with residual monosulfides and catchment organic loads Recreational boating: Will not address shallowing	Temporary structure that is easily reinstated, e.g. slatted fences to catch seagrass; netting (litter traps used in Yarra) Temporary bunding or artificial closure of estuary	Some capital cost in establishment. Costs depend on approach. Could be as little as \$25,000/yr ongoing cost.	Yes Could have implications on artificial management of estuary opening.	Seasonal. Would need ongoing operation and maintenance while estuary was open.	No
			Permanent structure E.g. piles at oblique angle	Unlikely to be practical			
3b Assist closure through installation of roughness (resistance) along rock wall	Relatively low cost Mimics previous system Difficult to demonstrate that this intervention will reinstate 'natural' conditions. Will not prevent further ingress of sea grass unless combined with 1b	Odour: Yes will prevent odour if successful Fish kills: Will require complementary catchment based program for long term success Recreational boating: Yes will reduce influx of sand into estuary and improve depth of water for recreational boating	Interim / trial works comprising sand, sand bags or rock	Up to \$50,000	Yes	Limited as these would only be temporary (one season only)	NA
			Permanent works: Rock or timber groynes attached to existing rock wall, spaced at 30 m intervals, extending approximately 5m into low flow channel	\$100,000 to \$250,000	Yes Hard to calibrate resistance level and degree to which option impacts on opening and closure	Some short term. Reducing in long term May require adjustment over time increasing/decreasing length.	Potentially yes, subject to further analysis and design



4.4 Other investigations

There are a number of additional investigations that could be undertaken to increase the confidence around the assumptions made in this investigation and/or to refine the details of the possible management actions. These investigations could contribute to the resolution of the issues at hand, but are not essential for the implementation of the short term program of works.

Table 7. Possible further investigations for Merricks Creek

Assumption / action	Possible further investigation
Understand water quality, through spatial and temporal extents	Use a data logger to collect high temporal resolution water quality information (dissolved oxygen, temperature, salinity, pH, turbidity). This will help develop a clear understanding of the Estuary's water quality spatially and temporally to better support management decisions.
Sea grass is the primary driver of the sulfate reduction / decomposition process	Seagrass has a lot of heavy carbon therefore could measure isotope ratio of CO ₂ in estuary (compared to phytoplankton or terrestrial). This would be performed by water quality sampling throughout the estuary and sampling a transect along the estuary to create a Keeling Plot. This approach has been implemented successfully at other locations, including Westernport Bay. It would help develop a detailed understanding of the influence of seagrass on hydrogen sulfide generation.
Presence and extent of acid sulfate soils	Bed sampling to confirm the presence (or absence) of acid sulfate soils. Core analysis would provide more information on the depth of acid sulfate soils present throughout the estuary. This would ensure the appropriate management actions regarding acid sulfate soils.
Coastal processes at estuary mouth – movement of sea grass	Photo monitoring over time, and in particular after storm events, at the mouth and along the beach would demonstrate the sea grass movement. Tracers on the beach (using ribbons with a similar density to sea grass) could also be used to monitor sea grass movement. This process could also be simulated for different storm events in a hydrodynamic model. Such a model could be calibrated using the results of the photo point and tracer monitoring. This would provide a robust understanding of the coastal process and potential prediction of the opening and closing regime under different future scenarios.

4.5 A note on governance arrangements

There are four agency groups responsible for the management of the Merricks Creek system (Table 8). All of these agencies have been involved in this project. These organisations will need to continue to work together, and with the community, to effectively implement any of these actions and work towards a healthy estuary for all stakeholders.

Table 8. Agency responsibilities

Agency	Authority/ purpose	Role in Merricks Creek
Melbourne Water	Manage water supply catchments, treat and supply drinking and recycled water, remove and treat most of Melbourne’s sewage, and manage waterways and major drainage systems in the Port Phillip and Westernport region.	Waterway and estuary manager. Lead in this project.
Department of Environment, Land Water and Planning (DELWP)	DELWP manages Victoria’s water resources in partnership with a network of government agencies and water authorities. They manage groundwater, catchments and waterways, infrastructure, water saving and re-use projects, flood management, governance and water legislation	Responsible for coastal infrastructure
Southern Rural Water	Manages rural water supply and delivery on behalf of the Minister of Water.	Responsible for dam registrations and licences
Mornington Peninsula Shire Council	Local government handles community needs like waste collection, public recreation facilities and town planning. This also extends to stormwater and infrastructure management. Local government have a statutory obligation to manage public health and related environmental health such as odours and noise.	Responsible for local services Responsible for stormwater management Responsible for public health

5 Conclusions and recommendations

5.1 Issues and desired outcomes:

Members of the community have raised concern regarding a persistent odour in the estuary that has been present over the period 2011 to 2015, ongoing fish kills in the system and recent reductions in depth of water for recreational boating.

5.2 Processes

Balnarring Beach and the Merricks Creek estuary are located in an area that naturally accumulates sea grass. The floating / available sea grass production has increased over the period 2007 to 2015 as a result of a period of increased storminess in Westernport Bay.

The combination of applied energy from waves, tides and stream flows has contributed to an open estuary over the period 2010 to 2015. The rock wall could be leading to increased energies at the estuary mouth. The open estuary has allowed the influx of:

1. available sea grass, and
2. sand

The influx of sea grass to the estuary has increased the rate of organic matter decomposition and anoxic production of black sludge and hydrogen sulfide in the Merricks Creek estuary. The production occurs both under the wet high tide conditions and the within the large masses of sea grass material that has accumulated in the estuary that remain damp during low tide. In addition the low tide conditions provide for the release of trapped hydrogen sulfide and the oxidation of the monosulfides and the release of additional sulfidic gasses.

It is unlikely that catchment based sources of organic matter are the dominant cause of the recent persistent odour in the estuary. Such sources would have resulted in persistent odours prior to the period post 2012. This is not to suggest that organic matter from the catchment is not a problem. Such catchment based sources are likely to be the dominant source of new organic material to the estuary once it is closed, contributing to algal blooms, associated low dissolved oxygen conditions and fish kills.

The open estuary condition has also allowed for some tidal pumping of sand into the estuary. This influx of sand and the tidal variation in water depth have contributed to the establishment of low water depths that have limited recreational boating (rowing and paddling).

5.3 Options and recommendations

The community has sought to achieve a reduction in the persistent odour in the area of the estuary, improved recreational boating (through increased estuary depth) and reduced fish kills. However, due to the complexity of the issues and processes, we have found no simple solution that satisfactorily achieves these management outcomes.

We do not recommend removal of sea grass from Balnarring Beach before it can enter the estuary as a means to prevent the odour production. The beach and sea grass provides habitat for the Hooded Plover that would be impacted by removal operations.

We do not recommend options to capture and remove the sea grass from within the estuary as this would be extremely complex, and require ongoing management and maintenance.

We prefer an option that focuses on achieving estuary closure as the primary mechanism to prevent sea grass entering the estuary. Such an approach would also address the water depth and conditions for recreational boating. We propose that work to achieve this outcome occur as soon as practicable to prevent further influx of sea grass to the estuary.

However, closure of the estuary also poses some risks. These risks include nutrient accumulation, algal events and associated fish kills. Closure could also pose a public health risk this summer. These risks are discussed below.

Nutrient accumulation and algal events: In the long term we propose that the risks of nutrient accumulation and algal events be managed by:

- Allowing breaches of the estuary during flood events. Breaches of the estuary mouth (i.e. the natural opening of the estuary) during significant rainfall and runoff events will assist the beneficial flushing of nutrients from the estuary. As a consequence, we do not favour options and works that will permanently close the estuary.

We prefer options that assist the natural closure of the estuary, and allow opening of the system during significant runoff events. We propose the installation of works that replicate the 'roughness' provided by the lateral groynes that were present on the old timber wall as a means of trapping sand at the mouth of the estuary. This will assist closure and allow natural openings of the estuary.

- In the medium and longer term, we propose catchment management programs to reduce nutrient loads to the estuary.

Public health: We are concerned that hydrogen sulfide accumulations could cause a public health hazard this summer if the estuary is closed while there are significant amounts of sea grass present in the estuary and this is combined with very warm and still weather conditions. We expect that this risk will only be present in the short term during the period over which the existing sea grass within the estuary decomposes. Seagrass decomposition is expected to take about 100 to 200 days, so once we can stop the seagrass from entering the estuary in large quantities, the risk will cease after around 4-8 months.

At high concentrations, hydrogen sulfide is a hazard to human health and, at very high concentrations, can cause death. However, this could only occur in parts of the estuary that sit lower than the sand berm and in very still conditions where there is no wind.

While the likelihood of such high accumulations of the gas is low, the consequences could be very high. We rank the risk to public safety as high and recommend appropriate management attention to address this risk. The risk will be highest over the summer period with the potential for high rates of sea grass decomposition and with high numbers of campers and other holiday makers within close proximity to the estuary.

Any breeze through the estuary prevents the settling of hydrogen sulfide in low lying areas, and mixing it with air reduces the risk of gas accumulations. However, during very still evenings with no wind movement, it may be possible for hydrogen gas to not mix with air and to settle in low lying areas.

Over the period that the estuary has been open, the hazard associated with this settling has been low as the gas drains out through the open estuary mouth, preventing any significant accumulations. We are concerned that on a windless evening, the sand berm that has closed the estuary may prevent such 'drainage', allowing the accumulation of hydrogen sulfide.

We are also concerned about the potential for algal blooms and estuary water quality this summer with a closed estuary.

We propose two alternate options to address these short term risks.

Recommended options

Option 1: immediate installation of interim works to assist estuary closure, preventing new seagrass entering the estuary.

These works could then be removed to re-establish an open estuary over the forthcoming peak summer period and reduce the risk of adverse water quality and public health outcomes. More permanent or replacement works could then be installed in autumn. This option has the benefit of preventing the large load of sea grass currently on Balnarring Beach from entering the estuary and

hastening the conclusion of the decomposition process. However, it will result in duplication of effort as the works will need to be installed twice.

Option 2: delay the installation of works until after the summer of 2015/16.

This option avoids the potential duplication of effort but comes at the cost of allowing more sea grass to enter the estuary, delaying the conclusion of the sea grass decomposition.

Evaluation of options and deciding on the way forward

We propose that these two options be canvassed with the agency and community working group established for this project.

In addition to these options, and in the short term, we propose:

1. An **investigation** be undertaken (based on research from University of Melbourne) using the recently developed model to identify the extent to which the open estuary condition can be attributed to wave energy, tides and catchment inflows. The output from this investigation would be used to assist the design of longer term intervention works.
2. The development of longer term **design** arrangements for works to re-establish an estuary opening and closing regime, which reduces sea grass influx to the estuary without impacting on estuary openings during high flow events. We propose that these longer term works be installed in autumn 2016.

Table 9: Timelines of work completed and alternate management options

Timeline	Action	Outcome	
Actions undertaken	May 2015	1 st Working Group meeting	Working group established and concerns raised
	Jun 2015	2 nd Working Group meeting	Project brief developed and desired outcomes agreed
	Jul 2015	3 rd Working Group meeting	Initial observations discussed and priority areas for further detailed investigation identified
	Aug 2015	Expert Panel engaged	Expert panel contributed expert science and specialist knowledge
	Oct 2015	4 th Working Group meeting	Findings and recommendations discussed and management actions agreed on.

		Option 1: Immediate interim works	Option 2: Delay works until after 2015/ 16 summer
		<i>Advantages:</i> <ul style="list-style-type: none"> Prevents further seagrass entering estuary over Nov/Dec Earlier resolution of odour issue <i>Disadvantages:</i> <ul style="list-style-type: none"> Duplication of effort 	<i>Advantages:</i> <ul style="list-style-type: none"> Less cost, more efficient use of limited resources <i>Disadvantages:</i> <ul style="list-style-type: none"> Odour will be around for longer
Timing	Investigations		
Oct 2015	Co-ordinate arrangements		No physical works
Nov 2015	Explore model to better understand cause of persistent estuary opening	Install interim works to assist estuary closure and stop more seagrass from entering estuary	
Dec 2015	Monitor and evaluate results of interim action	Remove interim works to reduce short term adverse public health and water quality risks over peak tourism season	
Jan 2016	Refine approach to longer term works to implement based on investigations		
Feb 2016	Monitor long term solution.	Implement longer term works solution	
Mar 2016			

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Attachment A
Background review for this investigation

Background review for this investigation

The observations discussed in section **Error! Reference source not found.** were drawn from consultation with community members, a site visit, and previous reports. Some details of this stage is provided here.

A site visit to Merricks Estuary was undertaken on 24th June by Ross Hardie and Amanda Shipp from Alluvium, and Paul Hodgson from Melbourne Water. The aim of the site inspection was to visit all three reaches of the study area and gather observations from some community members. Table 10 outlines the itinerary for the site inspections.

Table 10. Site inception locations

Contact	Locations visited	Reach
Geoff Hall	Estuary Mouth at Somers	Reach 1
Don Phillips	Balnarring Beach – including estuary at Balnarring Campground C and tidal extent just upstream of Balnarring Beach bridge	Reach 2
Karri Giles	Balnarring Beach, upstream of Balnarring Beach Road	Reach 3
Brian Thomas	Coolart wetlands, Tulum Creek	Reach 2

The following reports and community submissions were used to understand the issues, previous works and findings at Merricks Estuary.

Table 11. Bibliography used in background review

Year	Title	Author	Organisation
2015	Merricks Creek Estuary-Low Weir Option	Don Phillips	Working Group submission
2015	Merricks Creek and Estuary Working Group Notes and Observations	Geoff Hall	Working Group submission
2015	Items for consideration in the Merricks Creek Estuary independent study	Don Phillips	Working Group submission
2015	Items for consideration in the Merricks Creek Estuary independent study	Karri Giles	Working Group submission
2015	Items for consideration in the Merricks Creek Estuary independent study	Alan Dalton	Working Group submission
2015	Items for consideration in the Merricks Creek Estuary independent study	Russell Mein	Working Group submission
2015	Merricks Creek and Estuary Update on odour issue and call for members of the community to join a Working Group	Melbourne Water	Melbourne Water
2012	Replacement of timber training wall with rock sea wall	Aitkins Maritime Engineering	DSE / DELWP
2011	Merricks creek Entrance Coastal Processes Review	Water Technology	DSE / DELWP
2011	Merricks creek Entrance Hydrologic Study	Water Technology	DSE / DELWP
2011	Inspection Report for Timber Groyne/ Fence Merricks Creek, Sommers	Ainley projects	DSE / DELWP
2011	Understanding the Western Port Environment	Melbourne Water	Melbourne Water
2007	A fish survey of the Mornington Peninsula	Streamline Research	Melbourne Water

2007	Distribution and Conservation Significance of Frog Species on the Mornington Peninsula, Victoria	Annette Aboltins and Aaron Organ Ecology Partners	Melbourne Water
2007	A review of knowledge of selected estuaries in the Port Phillip Bay and Western Port Bay regions	Helen Arundel & Jan Barton Deakin University	Melbourne Water
2005	Westernport Catchment Water Quality Trend Analysis	Elise L King and J Angus Webb Water Studies Centre Monash University	Melbourne Water
2003	Merricks Creek Estuary Investigation into Management of Spit Erosion, Creek Scour and Water Quality Improvement Opportunities	GHD	Melbourne Water
2001	Creating a catchment community: An Action Plan for the Merricks-Coolart Catchment Group. Volume 1- report	Pamela craven, Yasmin Kelsall & Nicola Thomson	Monash University
1998	Waterway Assessment In The Western Port Catchment The Environmental Health Of Western Port Peninsula Streams	Rod Hardwick Australian Water Technologies	Melbourne Water
1966	Merrick Creek 1966 aerial photography	Melbourne Water	Melbourne Water
Unkn wn	All Our Sommers. A History of Sommers, Victoria	Bruce Bennett	N/a
1959	Parish Plans: Bittern Sheet 2		Dept. of Lands and Survey

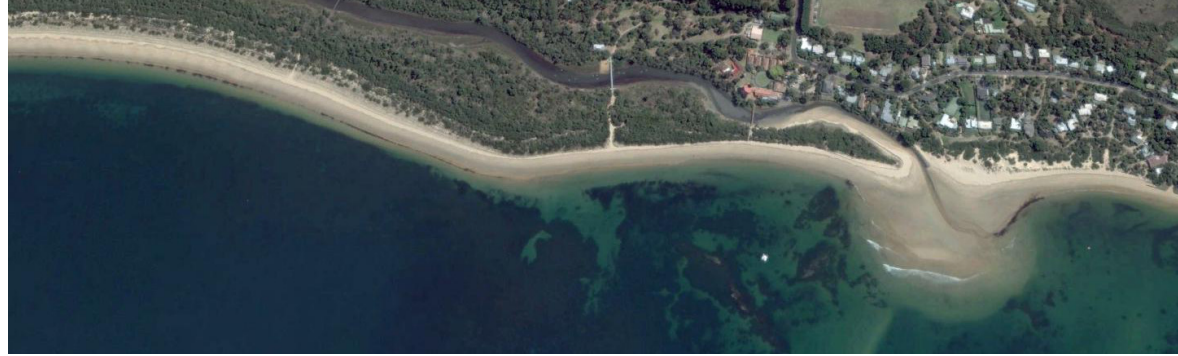

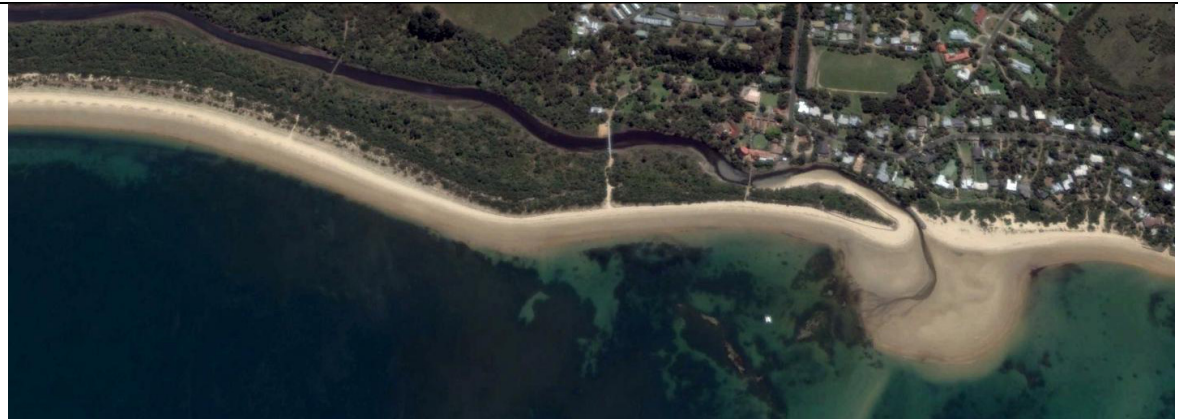


Attachment B






Review of sea grass accumulations on Balnarring Beach







Merricks Creek at Somers



	Little or no seagrass on foreshore		Abundant seagrass on foreshore
Feb`15		Jun15	
Dec14		May15	
Nov14		Aug14	
Apr14			

	Little or no seagrass on foreshore		Abundant seagrass on foreshore
Feb14			
Jan14			
Mar13			
Oct12		Sep12	

	Little or no seagrass on foreshore		Abundant seagrass on foreshore
Oct10			
Feb10			
Jun09			
		Aug06	

Critical months for seagrass appear to be August and September. However 2015 has been a very extended season starting in May and running through to September.

Attachment C Nutrient load calculations

Nutrient load calculations

Introduction

The relative nutrients that flow into the Merricks Creek Estuary are an important factor in the context of the odour generated in recent years in the Merricks Creek Estuary.

While there was no specific nutrient sampling available, it is possible to estimate, in a very basic manner, the relative loads of nutrients that enter the estuary. This attachment outlines the relative contribution of the four sources of nutrients. Due to the complexity of nutrient cycles, and the spatial and temporal variability, it is quite difficult to collect empirical data to verify these relative loads.

The four nutrient sources are:

- Seagrass
- Discharges from the local sewage treatment plant
- Stormwater flows
- Upstream rural runoff

Method

The method to quantify the relative loads was to consider, at the annual time scale, typical concentrations and loads using available literature and an analysis of GIS data to quantify catchment areas.

Seagrass. The volume of seagrass is estimated through an analysis of aerial photography and site visits to estimate the coverage and depth of seagrass in the estuary. Then using published literature, we estimate the relationship between the volume and the kilograms of nitrogen.

Stormwater. We estimate the loads of nitrogen in stormwater using a relationship between the impervious area around Balnarring (from aerial photography), and then multiple that area by an annual rainfall, runoff coefficient and also a typical concentration of nitrogen in stormwater flows.

Rural. We estimate the loads of nitrogen from the whole catchment by multiplying the catchment area (from aerial photography), by an impervious fraction, then multiple that area by an annual rainfall, runoff coefficient and also a typical concentration of nitrogen from rural land.

Sewage Treatment Plant. We estimate the loads of nitrogen from the sewage treatment plant by assuming that 250 houses in the region contribute, every day, 75% of the potable water, to sewage, and that using the EPA code of practice that discharges from that volume should be approximately 5 mg / L. This assumes there are no losses in that process, which is therefore probably over estimating the load.

The key inputs to the equation to estimate the volume of nitrogen (which was a common parameter across the four sources) are described below.

Table 12. Parameters used in estimating nutrient loads

Source	Equation to quantify loads	Parameters	Comment / References
Seagrass	Volume x Concentration x Density	Volume = 63,170 m ³ Concentration = 2% N Density = 23 kg / m ³	Nitrogen and carbon content of seagrasses taken from Duarte C.M., 1990. Seagrass nutrient content. Marine Ecology Progress Series · October 1990. Volume 67pp 201 – 207.
Sewage Treatment Plant	No. of properties x Water consumed per lot x Sewage generated (%) x Concentration	No of properties = 250 Water consumed = 125 l / day Sewage generated = 75% of potable Concentration = 5 mg / L	Nitrogen concentrations from STP sourced from EPA publication on “Code Of Practice For Small Wastewater Treatment Plants” (http://www.epa.vic.gov.au/~media/Publications/500.pdf)
Stormwater	Impervious area x Annual Rainfall x Runoff coefficient x Concentration	Impervious area = 7.35 ha Annual Rainfall = 721 mm Runoff coefficient = 60% Concentration = 3 mg / L	MUSIC Guidelines and Duncan (1999).
Rural	Catchment area x Impervious fraction x Annual Rainfall x Runoff coefficient x Concentration	Impervious area = 520 ha Annual Rainfall = 721 mm Runoff coefficient = 15% Concentration = 4 mg / L	MUSIC Guidelines and Duncan (1999).

Results

The results indicate there are orders of magnitude between the potential sources of nitrogen (as a common parameters).

As there is a lot of uncertainty and variability around these parameters, some sensitivity analysis was conducted to test “high” and “low” parameters. This provides an indicative range (on an annual basis).

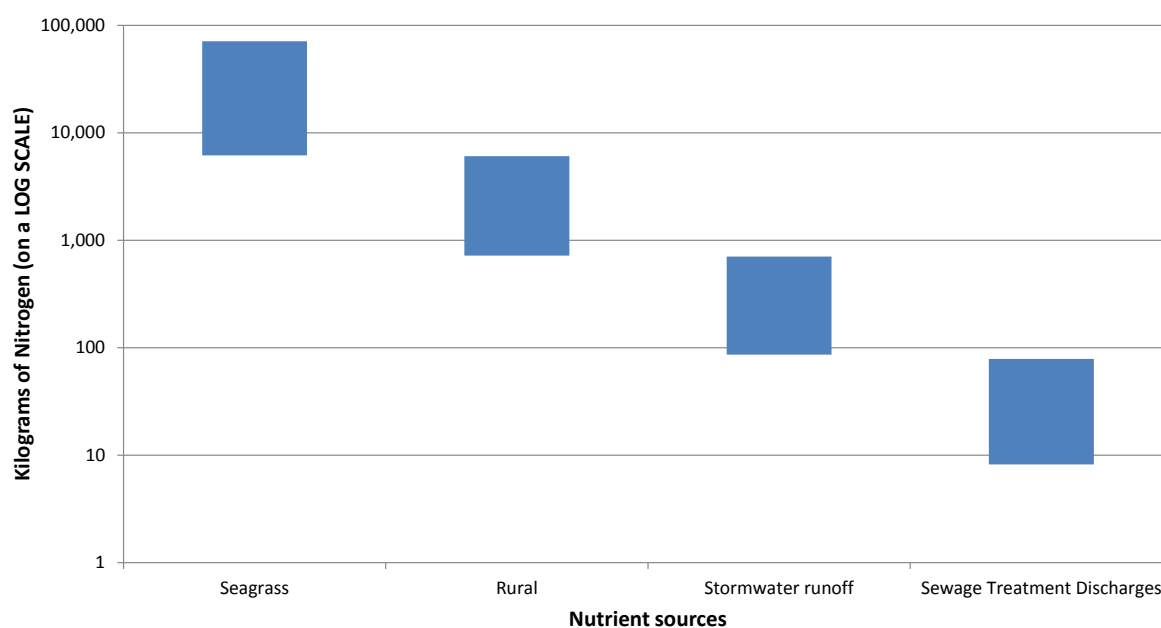


Figure 39. Relative loads of nutrients into Merricks Creek Estuary (Note this is a log scale)